CONSULTANT REPORT

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Public Interest Energy Research
CALIFORNIA ENERGY COMMISSION

Renewable Energy

PHOTOVOLTAIC CHARGEPORT DEMONSTRATION

Gray Davis, *Governor*

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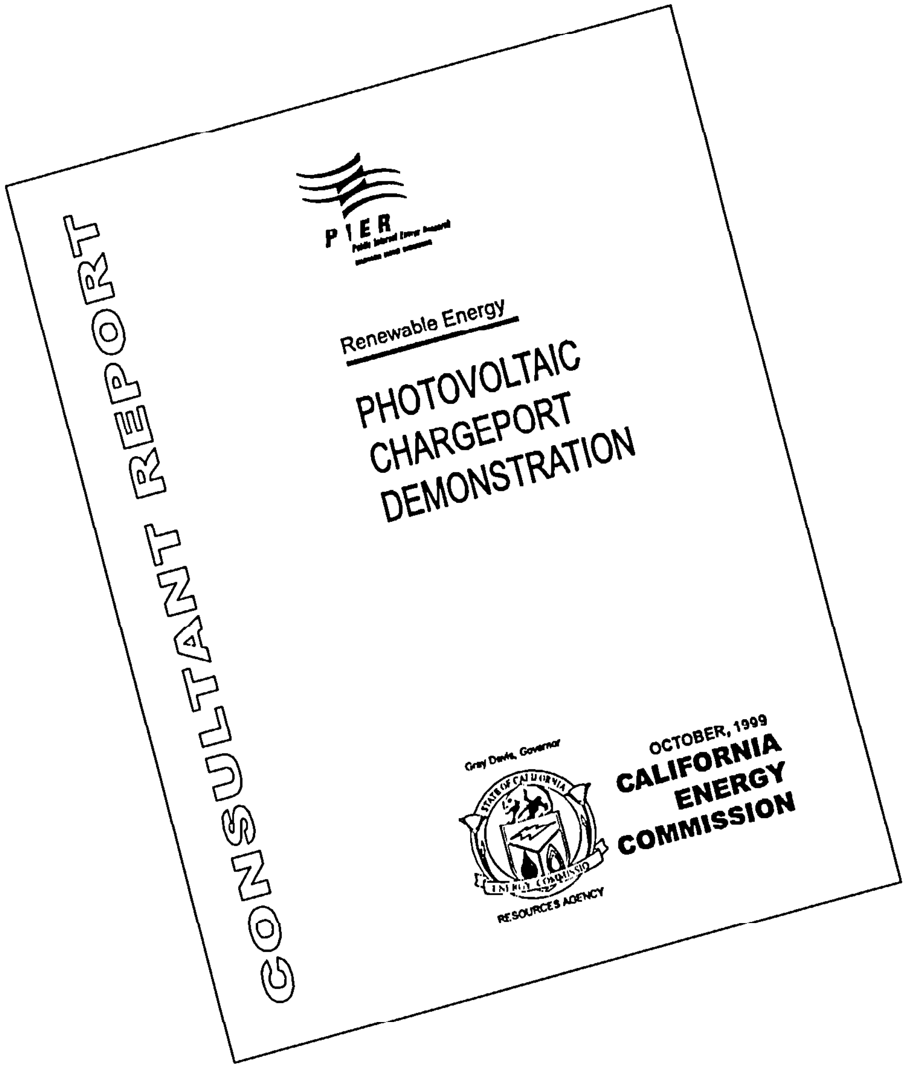

CALIFORNIA ENERGY COMMISSION

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Legal Notice

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliability energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million through the Year 2001 to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

In 1998, the Commission awarded approximately $17 million to 39 separate transition RD&D projects covering the five PIER subject areas. These projects were selected to preserve the benefits of the most promising ongoing public interest RD&D efforts conducted by investor-owned utilities prior to the onset of electricity restructuring.

What follows is the final report for the Photovoltaic Chargeport Demonstration project, one of six projects conducted by San Diego Gas & Electric. This project contributes to the Renewable Energy Technologies program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

Executive Summary

According to the California Air Resources Board (CARB) Electric Vehicle fact sheet 1998, nearly 90 percent of Californians live in areas that do not meet the air standards set by Federal and State governments. CARB established the goal that by the year 2003 ten percent of all new vehicles sold in California would be zero-emission. Electric vehicles (EVs), an emission-free alternative to internal combustion engine vehicles, may help achieve this goal.

EV performance closely matches that of conventional vehicles, but their range is limited to from 60 to 80 miles between recharges To promote widespread use of EVs in California, it will be necessary to create a charging infrastructure.

The San Diego Gas & Electric (SDG&E) photovoltaic (PV) covered parking structure (Chargeport) is designed to operate in parallel with the electric grid and provide continuous power to charge EVs in a public area. By helping to develop charging infrastructure, the Chargeport promotes the widespread use of EVs.

The PV Chargeport is located at the San Diego County Administration Center in downtown San Diego, near the Lindbergh Field International Airport and San Diego Bay. EV charging is provided at no cost to the end user. The six charging stations in the Chargeport can provide more than 120 charges per month.

The demonstration integrated two emission-free technologies, EV and PV, to provide San Diego residents with a conveniently located charging station for their EVs.

Project Purpose

This project demonstrated the use of PV roofing panels to provide power to an EV charging station. The goal of the demonstration and field testing of current design methodology was to establish guidelines for future deployment of EV charge stations that use PV and that don't require extensive engineering.

Objectives

The objectives of this project were to:

- Construct and demonstrate a PV system integrated into a parking structure and connected to the utility grid that would offset the energy used to charge the EVs.
- Evaluate the potential for a PV Chargeport to supplement the electricity used to charge EVs
- Monitor and evaluate Chargeport performance including climate and solar parameters, system efficiency, and power production over a nine month period of operation

- Investigate and select a second site for a similar PV/EV Chargeport in Northern San Diego County
- Educate industry and the public on the benefits of PV systems and EVs.

Background

This project was funded through collaborative efforts between SDG&E, United Solar, and the California Energy Commission. Of the total $175,000 project cost, the California Energy Commission's Public Interest Energy Program (PIER) contract contributed $90,000 towards construction, project management, operation, and performance assessment.

SDG&E was the general contractor and project manager for the construction, operation, and maintenance of the Chargeport. The County provided a monthly payment to SDG&E for the Chargeport's maintenance.

A second demonstration site in the northern portion of San Diego County was originally planned, but SDG&E encountered difficulties in locating a site and the plan was abandoned.

The total cost of the demonstration Chargeport was $175,000 including $70,000 of project management, data analysis, and reporting. The estimated cost of duplicating the Chargeport is $105,000, which would be amortized over 20 years. Assuming a favorable economic scenario of an eight percent interest rate with zero inflation, the present value annual revenue requirements would be $22,500. The overall cost of energy from this facility would be nearly $4.58/kWhr.

The County expressed interest in ownership of the PV facility when the demonstration concluded.

Outcomes

Performance data were analyzed and potential benefits of the PV system were evaluated with the following results:

- We constructed an EV chargeport that integrated PV technology.
- Performance of the PV system was lower than anticipated
  - The peak output (3.5 kW) was about half the power (work) required to charge an EV
  - The PV system operated at less than four percent efficiency and at an average capacity factor of 13.5 percent.
- Cost of energy from the PV Chargeport was nearly two orders of magnitude greater than the cost of energy from the utility grid.
- We were unable to procure a second site in northern San Diego County and the plan was abandoned.

- The Chargeport promoted public awareness of the potential environmental benefits of the PV Chargeport and EVs.

Because of the low EV usage of the Chargeport during the demonstration, some of our results were inconclusive.

Conclusions

- For the PV system and carport components to be competitive in the market place, initial costs must be reduced by more than 50 percent.
- Potentially, an infrastructure of 1,000 Chargeports could reduce airborne carbon emissions by nearly 3.4 million pounds a year.
- With limited subsidy from solar technology programs, the initial cost of the Chargeport components could be substantially reduced.

Recommendations

- The Chargeport continues its operation.
- Establish cost targets that would make the PV/EV concept economically viable.

Abstract

A goal set by the California Air Resources Board is that ten percent of all new vehicles sold in California by the year 2003 will be zero-emission vehicles. Electric Vehicles (EVs) represent an emission-free technology that can be used to achieve this goal. To reach this goal and promote widespread use of EVs in California, a charging infrastructure needs to be developed. One technology option that could support this infrastructure would be parking structures, available to the public throughout California, which would provide shade as well as charging stations for EVs. Typically, these parking structures would be installed in public facilities and would use the utility grid as the power source. A second technology option, Photovoltaics (PV), offers an environmentally attractive solution to reduce the energy used for charging EVs.

The purpose of this San Diego Gas & Electric (SDG&E) project was to provide a PV covered parking structure (Chargeport) to demonstrate the practicality of integrating PV roofing panels to convert sunlight into electricity with charging stations to offset the energy used in charging EVs. This Chargeport was designed to provide covered parking and six charging stations for EVs.

The Chargeport was completed and inaugurated in September 1998 at the County Administration Center in downtown San Diego. Operations for the entire facility continued through September 1999, with no maintenance and therefore no down time required. The power and energy generated by the PV system can be delivered to the grid when EVs are not being charged. However, the value of a PV Chargeport to support the electric grid during the times when no EVs are charged is insignificant to a 12,000 Volt distribution system. Due to infrequent usage of the Chargeport for charging EVs during the nine-month demonstration period, the results of the data analysis, related to the acceptance of the Chargeport as a charging facility, were inconclusive

The California Energy Commission (Commission, Energy Commission), through the Public Interest Energy Program (PIER), contributed $ 90,000 towards the cost of this project.

1.0 Introduction

The California Air Resources Board (CARB) established the goal that ten percent of California's registered vehicles would be zero emission by 2003.

Although there has been significant progress since 1970 in reducing emissions per mile traveled in combustion engine motor vehicles, the number of cars on the road and the miles they travel have doubled in the same time frame. The challenge of meeting state and federal air standards in seriously polluted areas, such as Los Angeles, is so severe that even if every vehicle were to disappear from its streets, the city would have no chance of meeting environmental standards by the year 2000.

Electric vehicles (EVs) are an emission-free alternative to internal combustion engine vehicles. EVs are currently the only technology classified as zero emissions vehicles capable of meeting the 2003 requirements. They operate over 90 percent cleaner than the least-polluting conventional gasoline-powered vehicles.

The 10 percent results from the emissions produced when generating the electricity used to charge the EVs.

EV performance closely matches that of conventional vehicles, but their range is limited to between 60 and 80 miles before recharging is needed. To promote widespread use of EVs in California, it will be necessary to create a charging infrastructure.

The San Diego Gas & Electric (SDG&E) photovoltaic (PV) covered parking structure (Chargeport) was developed to provide San Diego residents with a conveniently located charging station for EVs. It integrates two emission free technologies—PV and EV—demonstrating an emission-free electricity generating option. Demonstration of the Chargeport's performance and cost would contribute to the development of the required charging infrastructure.

The PV Chargeport, capable of charging six EVs at once, is located at the San Diego County Administration Center (CAC) in downtown San Diego near the Lindbergh Field International Airport and San Diego Bay (Figure 1). The EV charging is provided free to the end user.

The facility was instrumented to collect performance data throughout the nine-month demonstration period. The demonstration was sited in a visible location to promote consumer awareness of PV and EV technology. Customer education on these technologies is important in gaining market acceptance in California.

Figure 1. Chargeport at the San Diego County Administration Center

1.1 Background

In 1996, SDG&E initiated the development of the Chargeport structure to provide covered parking and a charging facility for EVs. The covered parking would increase the public acceptance and allow the integration of PV technology. In 1997, SDG&E entered into a contract with the California Energy Commission as part of their Public Interest Energy Research (PIER) program to co-fund the installation and operation of the Chargeport on the San Diego CAC parking lot.

The San Diego board of supervisors offered to host this demonstration project to promote energy efficiency and help improve regional air quality.

United Solar Systems, a world leader in thin-film PVs, co-funded this project by providing the PV system. Their PV roofing product is ideal for Chargeport application because of its integrity of construction. It is sturdy, lightweight, unbreakable, and weather tight.

SDG&E previous experience with United Solar involved their Roof Integrated PV off-grid system at South Cardiff State Beach in 1997. Project performance exceeded expectations, and State Parks and Recreation purchased the system from SDG&E in the spring of 1998.

Other SDG&E projects with PV technology included a condominium complex in which PV's supplied a portion of owner energy; a tracking trough solar system installed at a high school as a energy management and education tool; and various tests of PV systems at its research and development labs.

1.2 Project Purpose

This project demonstrated the use of PV roofing panels to provide power to an EV charging station. The goal of demonstrating and field testing current design methodology was to establish guidelines for future deployment of PVs for EV charge stations without requiring extensive engineering.

SDG&E proposed the Chargeport concept to promote the widespread use of EVs in which existing technologies could be integrated to provide a facility that would be attractive and practical for consumers.

1.3 Technology Concept

The underlying concept included integration of PV technology in a covered structure with EV charging stations and power inverters that provided excess energy to the electric grid.

The PV system used in this project included an integrated solar roofing product provided by United Solar, a standard metal frame structure for the carport, and trace DC / AC inverters.

United Solar's multi-junction technology was selected as the roofing material for the project. Advantages of using this PV technology over single crystalline or like PV technologies included:

- Lightweight material (less than 2 pounds per square foot) that reduced structural requirements.
- A rugged, unbreakable surface to reduce the risk of vandalism
- Weather tight roofing that provided a complete weather seal for the structure

The PV technology used in this project consisted of multi-layer thin-film solar cells constructed of three separate type amorphous semiconductor solar sub-cells. Each cell has a different spectral response characteristic and forms a lightweight panel.

The trace inverters are off-the-shelf components that provide 240 VAC, 60 Hz to the electric grid. Delco and EVI provided both the inductive and conductive charging stations.

1.4 Project Approach

The Chargeport concept would provide a modular, flexible prototype unit with two, four, or more charging stations, both inductive and conductive, integrated into a freestanding carport. Located in public areas for ease of accessibility and visibility (shopping centers and employee parking facilities), the carport would encourage consumers to purchase EVs.

The use of PVs as an integral part of the Chargeport would provide an environmentally responsible solution to providing the energy needed to charge the EVs.

1.5 Project Objectives

The objectives of this project were to:

- Construct and demonstrate a PV system integrated into a parking structure and connected to the utility grid that would offset the energy used to charge the EVs.
- Evaluate the potential for a PV Chargeport to supplement the electricity used to charge EVs
- Monitor and evaluate Chargeport performance including climate and solar parameters, system efficiency, and power production over a nine month period of operation
- Investigate and select a second site for a similar PV/EV Chargeport in Northern San Diego County
- Educate industry and the public on the benefits of PV systems and EVs.

2.0 Discussion

The 5 kW Chargeport is a unique design that applies the United Solar triple junction PV roofing panels, to provide a portion of the electricity used by six (three inductive and three conductive) EV charging stations, and is also interconnected to the electric distribution grid. These roofing PV panels provide the roof support for the parking structure

The Chargeport is connected to the electric distribution grid. Electricity from the PV system is fed into SDG&E's electric grid when the energy generated by the PV system is not being used to charge EVs.

2.1 Site Selection

The criteria used by SDG&E for site selection included:

- A customer host site with existing electric utility service with 208 or 240 V available power panels near the Chargeport to minimize construction cost of the electric interface
- Adequate parking facilities accessible for public use without disrupting other parking activities
- Appropriate protection from potential EV damage from battery acid leaks or charger station fire
- A facility where the Chargeport would be prominently and easily identified as a public EV charging station, but with a degree of security against vandalism
- A host that would be agreeable to negotiate the purchase of the Chargeport at the conclusion of the demonstration and continue its operation
    - Site owner's interest in EVs and in maintaining the Chargeport
    - Demographics of the region
    - Proximity to a major transportation thoroughfare
    - Accessibility to the public
    - Accessibility to the utility grid.

The San Diego County Administration facility in downtown San Diego was seen a strategic location to promote the use of EVs with a Chargeport that would be flexible to meet future demands. This site met all of the site selection requirements including a host willing to consider continued use of the facility after the demonstration period.

The San Diego Board of Supervisors agreed to host this demonstration project to promote energy efficiency and contribute to improving regional air quality.

The location offered by the CAC parking area met the demographics (space effectiveness, proximity to major thoroughfares) and accessibility to the public criteria. The parking lot--located only blocks from public transportation, a major freeway, and downtown businesses--provided San Diego residents a convenient location for daytime charging.

The CAC agreed to provide electricity from the utility grid and the PV system at no cost to the user charging an EV for one year beginning September 1998. At the conclusion of the initial demonstration, the San Diego Board of supervisors agreed to extend the use of the Chargeport through December 2000.

San Diego County had anticipated adding a fleet of EVs for employee use. The San Diego County Administration facility in downtown San Diego was seen a strategic location to promote the use of EVs with a Chargeport that would be flexible to meet future demands. This site met all of the site selection requirements including a host willing to consider continued use of the facility after the demonstration period. As of December 1999, San Diego County has not yet adopted their EV fleet program.

The CAC also agree to provide the energy to charge EVs at no cost to the end-user for a period of one year beginning September 1998. This was extended as a result of the decision by the San Diego board of supervisors to extend the demonstration of the Chargeport.

2.2 Selection of Second Site in North San Diego County

SDG&E assessed a second site in the northern part of their service territory. The second site was intended to encourage use of EVs throughout San Diego County and expand the exposure of the integrated Chargeport technology.

We used the same criteria for the selection of the second site as we did for the CAC site.

SDG&E encountered difficulties with the locating a site for a second Chargeport. Also, it was anticipated that United Solar would again contribute the PV panels for the second site, and would supply SDG&E with engineering support. But in mid August 1998, United Solar moved its headquarters out of San Diego and was no longing interested in participating in the second site.

Several attempts to negotiate a location were declined by local businesses such as COSTCO, the North County Fair and Rancho Bernardo Shopping Malls. Permitting and contracts agreements proved unsatisfactory to the potential hosts and SDG&E.

Although SDG&E asked for no initial capital costs from the potential host, the contract conditions required that they operate and maintain the site after monitoring and evaluation had been completed. Other concerns included the potential financial considerations of providing energy at no cost to the end-user and use of available space.

At the time we were seeking the second site, performance data on the CAC Chargeport were unavailable and we could not quantify the estimated cost to the host customer.

After several failed attempts in locating a host for the second site, it was decided by Project Managers from both the California Energy Commission and SDG&E that remaining funding would be better spent on the evaluation of the existing CAC Chargeport.

2.3 Construction of County Administration Center Chargeport

SDG&E served as prime contractor and project manager. We coordinated all activities for the site selection, construction, installation, operation, and maintenance of the Chargeport and EV charging equipment.

SDG&E was involved in all aspects of construction:

- Designed pre-construction and final structural plans
- Obtained all required permits for the CAC site.
- Finalized contracts including access to the site, maintenance responsibility, pricing of the generated electricity, ownership and disposition of the system at project completion.
- Supervised site preparation and construction
- Coordinated interconnection to the electric grid
- Coordinated the installation of Chargeport structure and PV panels

SDG&E's agreement with the county included a monthly payment to SDG&E for the maintenance of the PV Chargeport.

Although San Diego County has not implemented their EV fleet program, they expressed interest in owning the PV facility after the demonstration project had concluded; terms and conditions of the turnover to be determined at the end of the project. This decision was postponed until December 2000.

The United Solar PV Chargeport components (Figure 2) consisted of 42 SSR-120 modules, generating a total of five kW (rated at standard test conditions). The system contains one trace inverter, providing 240 VAC, 60 Hz power to the grid.

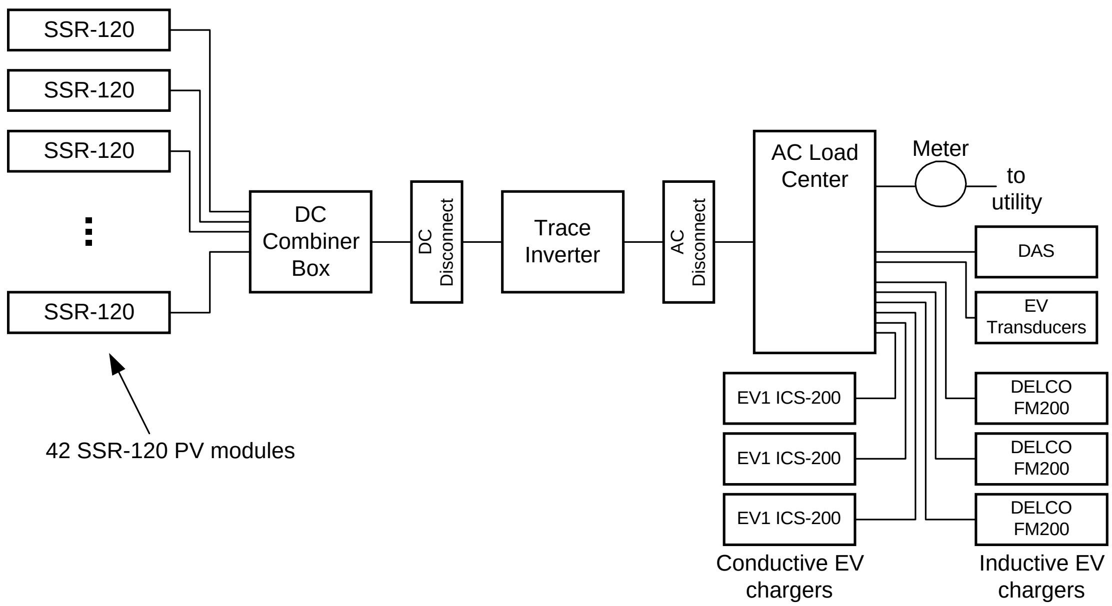

Figure 2. Block Diagram of Chargeport at the CAC

Construction of the Chargeport was completed and inaugurated in September 1998. The EV chargers are located underneath the PV structure to allow easy access for vehicles to the charging stations. The system is grid connected, to supplement chargers on cloudy days and allow excess energy produced by the PVs to be fed back into the utility grid.

The Chargeport's operation continued through September 1999. Unfortunately, less than 50 EVs in San Diego are owned by the general public and the facility downtown was not used as much as anticipated.

2.4 Methods

To assess the Chargeport's performance the following were monitored:

- Energy and power used by EVs
- Amount of available solar energy
- Energy produced by the PV system
- Energy used and delivered to the electric grid.

The amount of power required by a typical EV is around six kW, nearly double the available capacity from the PV system. The electric grid provided the additional required power.

During the periods when no EVs used the Chargeport, the energy produced by the PV system was delivered to the electric grid.

We investigated possible sites for a second Chargeport demonstration in the northern part of San Diego County. Several customers were contacted for this effort including COSTCO, Northeast Mall, and Rancho Bernardo Shopping Mall. None were interested in hosting the project because of the financial consideration of providing energy at no cost to the end-user and the amount of space used.

Permitting, contracts and location agreements proved unsatisfactory to both parties. Several attempts to negotiate a location were declined by local businesses. Two candidates withdrew during contracting stages due to the anticipated cost and permitting problems with the site.

Although SDG&E was asking for no initial capital costs from the business, after monitoring and evaluation was completed they would need to maintain the site with internal funding.

At the time we were seeking the second site, performance data showing energy generation was unavailable and we could not quantify the estimated level of energy cost burden the host customer would be assuming. Data Acquisition, Monitoring, and Evaluation

SDG&E subcontracted the monitoring of the Chargeport project to Paragon Consulting of La Verne, California.

Paragon was responsible for acquisition (performed remotely), analysis, and reporting of the data used to evaluate the system's performance. Performance monitoring included an assessment of balance of system reliability, availability, serviceability and durability. In data analysis, Paragon followed the standards and testing procedures determined by the utility photovoltaic group (UPVG).

Paragon used a remote communication system (standard telephone modem) to collect PV performance data on a daily basis from the Data Acquisition System (DAS). Data was collected in 15-minute intervals to profile energy production and use by EVs. This included environmental data to quantify the effects of local climate on the PV system.

Paragon communicated with SDG&E on a regular basis to report any degradation in performance. Data analysis of the DAS system, performed by Paragon, consisted of the parameters listed in Table 1.

Table 1. DAS System Parameters

Data Parameter	Measurement Units	Measurement Device
PV Output Power	Watts	Watt/Watt-hour transducer
PV Output Energy	Watt-hours	Watt/Watt-hour transducer
Solar Irradiance	Watts per meter^2	Pyranometer
Ambient Temperature	^{o}Celsius	Thermocouple
Cell Temperature	^{o}Celsius	Thermocouple
EV Power Consumed	Watts	Watt transducer (1 per EV charger)

2.5 Results

Data collection and analysis for the EV Chargeport at the CAC began in November 1998 and continued through July 1999. System performance was evaluated using six major categories:

- Energy production
- EV usage
- Temperature effect
- System efficiency
- System availability
- Capacity factor.

2.5.1 Energy Production

The Chargeport produced a total of 4,244 kilowatt hours (kWhr) during the nine months data was collected. The average monthly energy produced from the PVs was 471.6 kWhr. During the summer the PV system produced more energy because of the increased hours of sunlight. Figure 3 shows the detailed monthly energy produced.

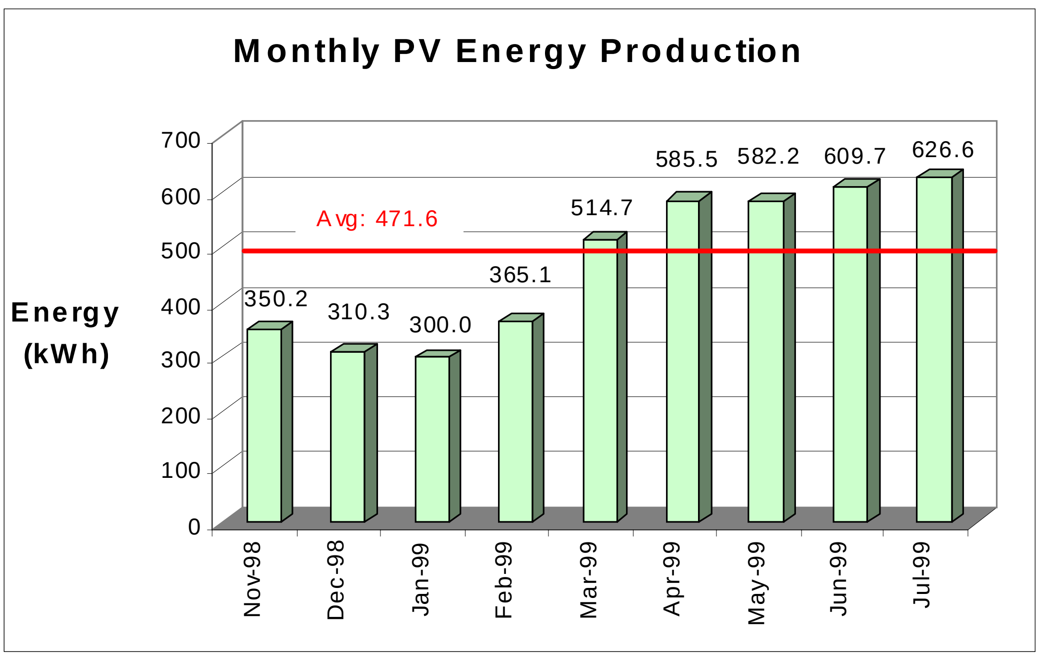

Figure 3. PV System Monthly Energy Production at the CAC Chargeport

2.5.2 EV Energy Consumption

The total energy used in changing EVs during the nine-month period of performance was 750.7 kWh. This equates to a monthly average of 83.4 kWhr. The energy is the amount of kWhrs consumed during a charge of the batteries. Figure 4 summarizes the actual energy produced by the PV system and the energy used in all six EV charger stations, from November 1998 to June 1999.

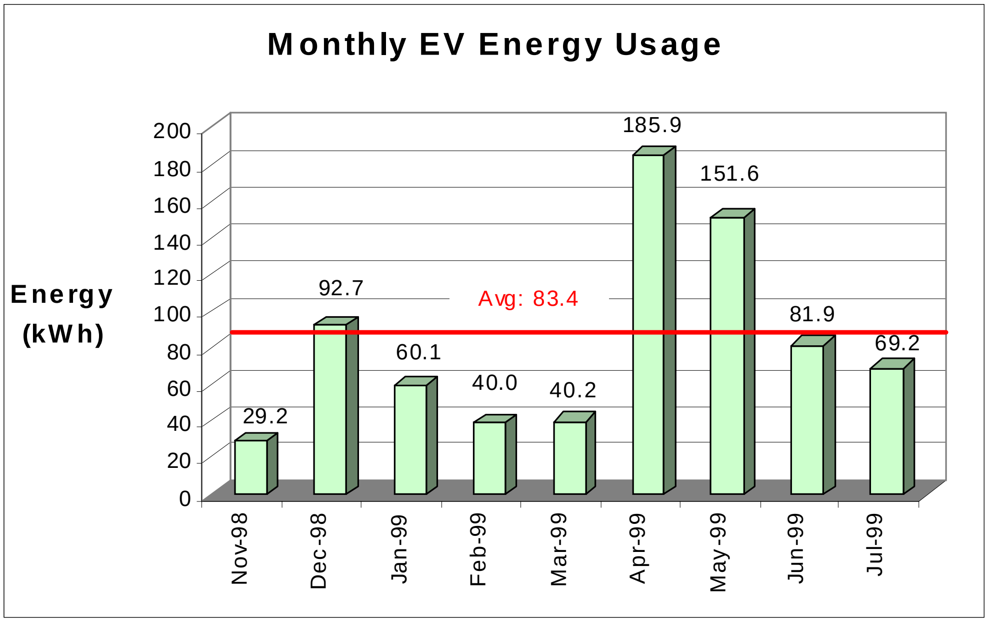

Figure 4. Monthly Energy used by EVs at the CAC Chargeport

Power demand can be considered as the amount of work necessary to move a load. Similarly, the power demand of the EV chargers is the amount of kWs required to charge the batteries in a given period of time. The lower the power, the longer the charge needs to be.

2.5.3 EV Charger Demand Profile

Figure 5 shows the power demand required by each charging station during the month of April 1999 was generally between 5 and 7 kW. The peak output of the PV system was measured at nearly 3.5 kW, which is about 50 percent of the power requirements to charge the batteries of an EV. The additional power to charge the batteries in a shorter period of time was provided by the utility grid.

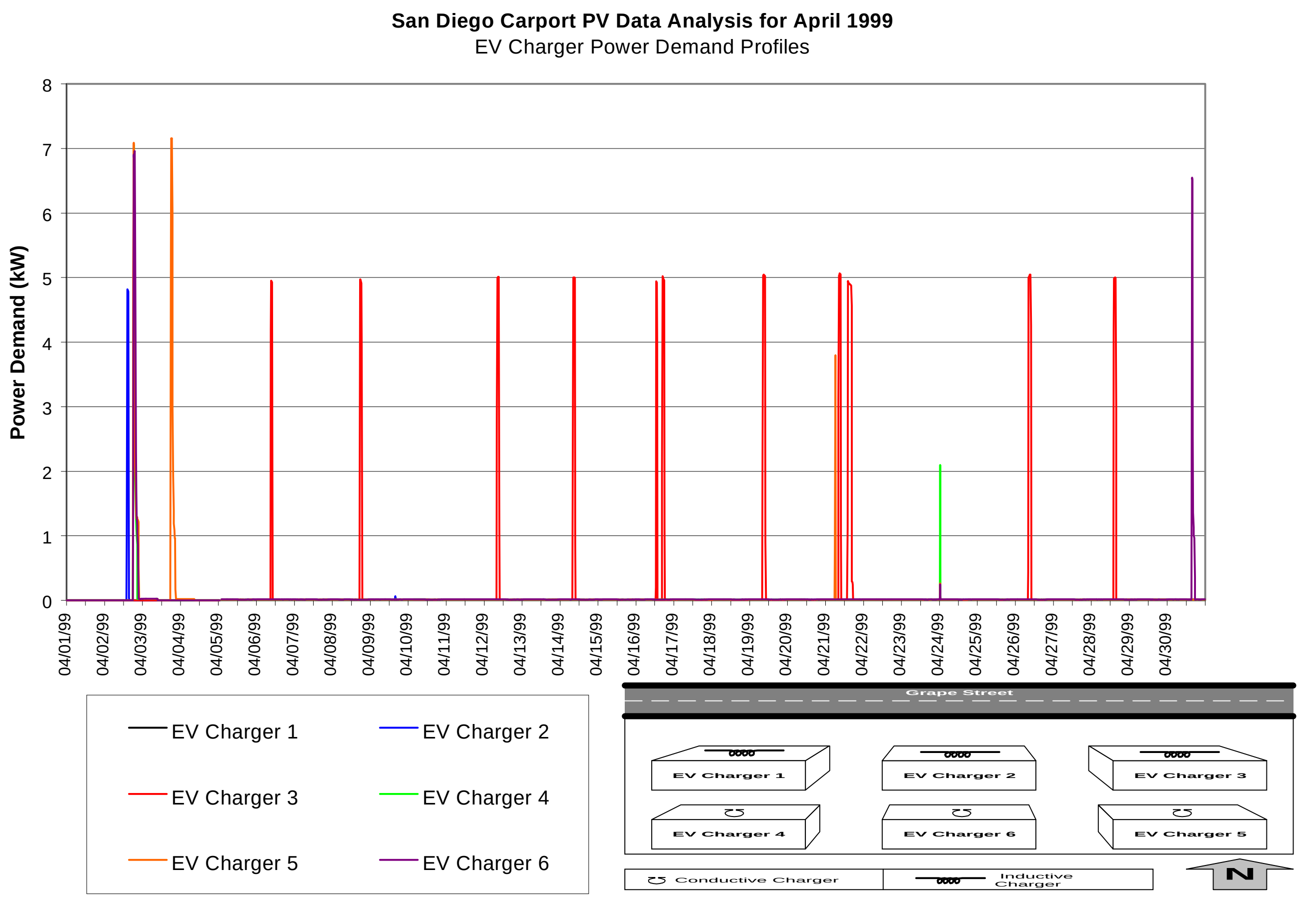

Figure 5. Chargeport Charger Station Demand Profile - April 1999

Figure 6 shows that the total energy produced by the PV system on a monthly basis was greater than the energy used in charging EVs due to a low usage of this facility. The excess electricity was fed into the electric grid.

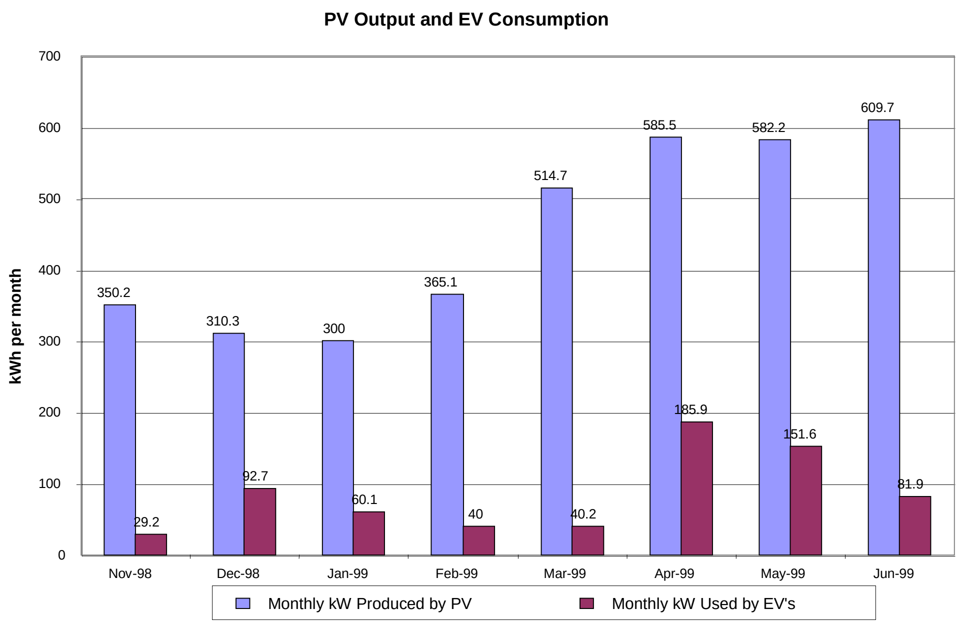

Figure 6. Energy Generated by the PV system and Energy Consumption

2.5.4 Temperature effects

The cell temperature has an inverse relationship to output power in PV arrays. This is another reason why the CAC, located near the ocean, is an attractive location for the Chargeport. Figure 7 (for April 1999) shows, that in a range of 50 W / m² solar irradiance, increased temperature result in decreased power output.

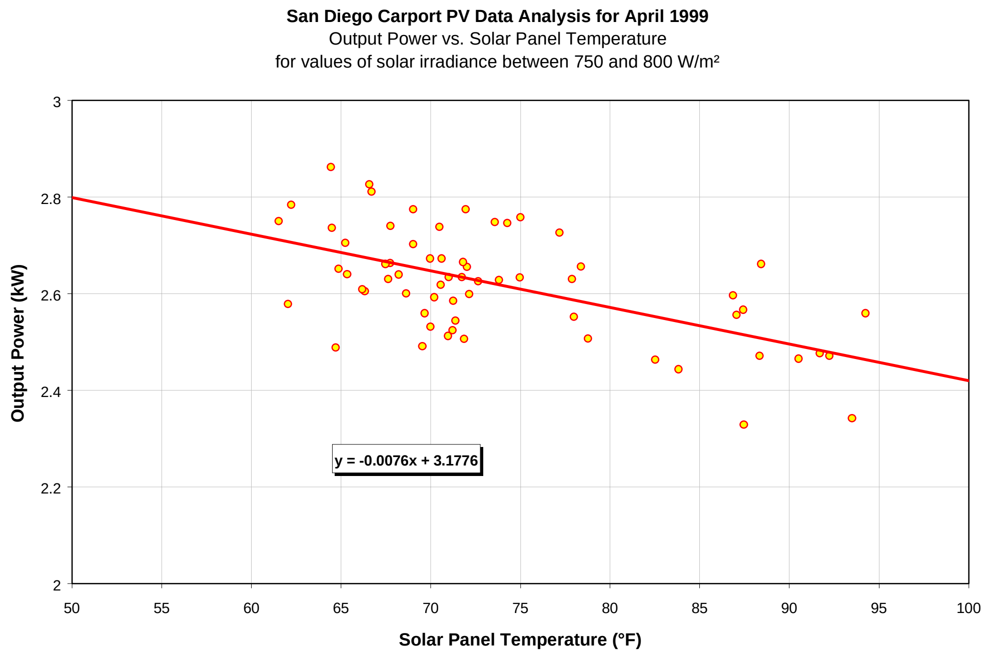

Figure 7. Temperature Effects

2.5.5 System Efficiency

System efficiency takes into account all the losses in converting solar irradiance to electrical power, as well as the balance of system component losses. System efficiency is calculated as follows:

$$\textbf{Efficiency (\%) = Output Power (Watts) / [SI (W/m}^2\textbf{) * SA (m}^2\textbf{)]}$$

Where SI is the solar irradiance measured, and SA is the surface area of the PV array. Each month, the system efficiency is plotted against the output power and for all values in which SI > 500 W/m^2, an average monthly value is calculated.

Efficiency of thin film PV products range between three percent and four percent. The data (Figure 8) indicates that the system performed during a summer month within the range of expected efficiency. The average calculated efficiency value from the data is 3.37% for July 1999.

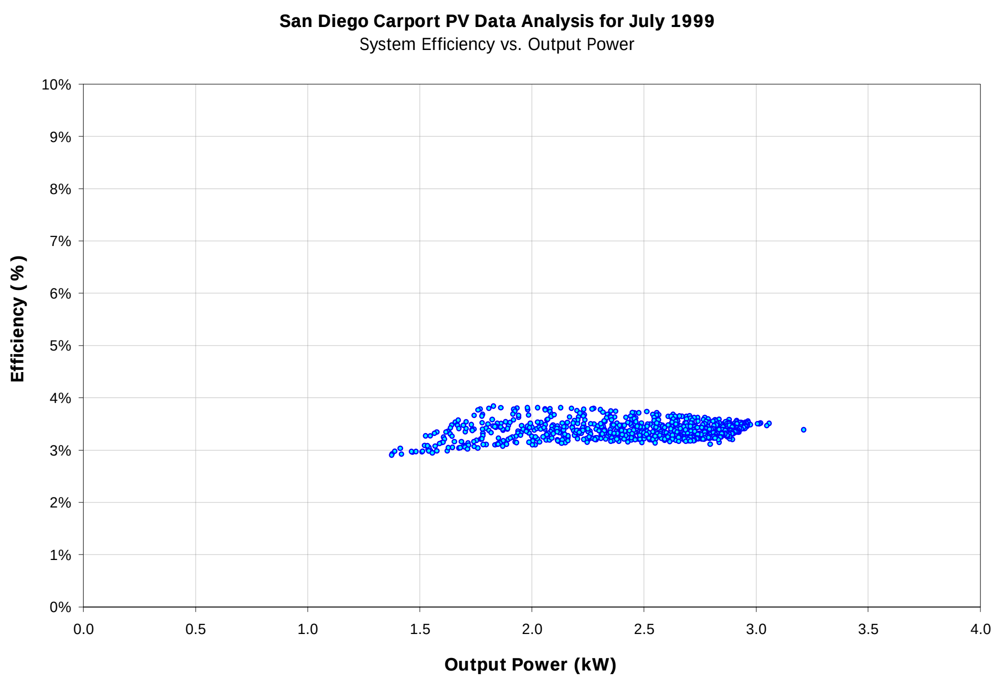

Figure 8. System Efficiency

Figure 9 compares efficiency and energy generated from November 1998 to July 1999. It is noticeable that efficiency drops slightly during the summer months because the cell temperature increases. The PVs system operates most efficiency under bright lights and cool temperatures, and so with higher temperatures in the summer months, there is more sunlight, more energy, but at a reduced efficiency.

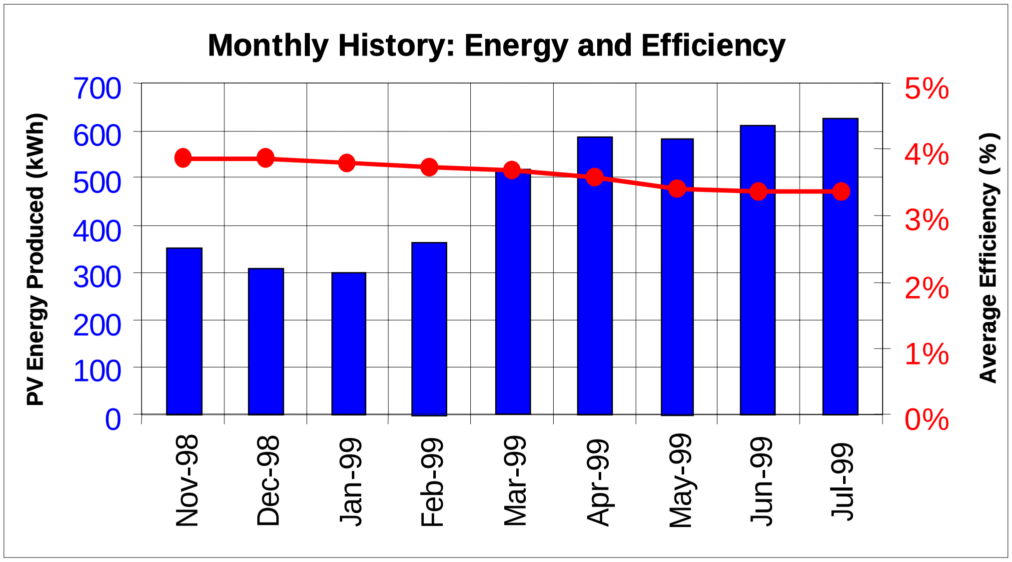

Figure 9. Historical Energy and Efficiency

2.5.6 Capacity Factor

Another measure of performance is the capacity factor. The capacity factor of a system is calculated by taking the measured energy available per day and dividing by the rated value.

Capacity Factor (CF) = [Total kWh/day (measured)] / [Rated kW * 24 hrs]

Whereas the availability of the system indicates how many hours the system was available to operate. The capacity factor provides information on the performance of the system compared to a baseline (rated power = 5.040 kW multiplied by 24 hours).

For each month, an average value was determined by averaging daily capacity factor. Over the nine-month period, June 1999 had the highest capacity factor, but the overall average capacity factor was 13.5 percent (Figure 10).

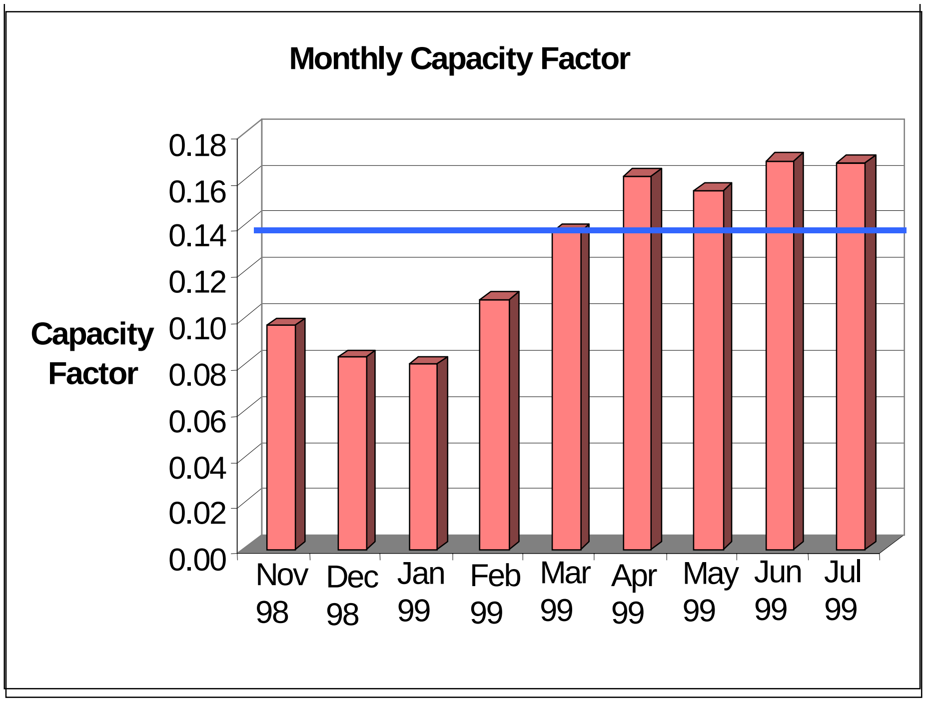

Figure 10. Monthly Capacity Factor

2.6 Project Outcomes

SDG&E demonstrated the successful integration of PV technology as roofing material for the construction of a parking structure for charging EVs. The CAC Chargeport was completed and inaugurated for public use in September 1998. System performance monitoring began in November 1998 and concluded in July 1999.

The system has been 100 percent operational with no maintenance requirements and without any outages. Performance data were analyzed and potential benefits of the PV system were evaluated.

Performance data were analyzed and potential benefits of the PV system were evaluated with the following results:

- We constructed an EV chargeport that integrated PV technology.
- Performance of the PV system was lower than anticipated
  - The peak output (3.5 kW) was about half the power (work) required to charge an EV
  - The PV system operated at less than four percent efficiency and at an average capacity factor of 13.5 percent.
- Cost of energy from the PV Chargeport was nearly two orders of magnitude greater than the cost of energy from the utility grid.
- We were unable to procure a second site in northern San Diego County and the plan was abandoned.
- The Chargeport promoted public awareness of the potential environmental benefits of the PV Chargeport and EVs.

The rate of use of the Chargeport by San Diego residents was disappointing. On average, the Chargeport was used for only ten charges per month by one to three vehicles. This low rate of use was caused by the small numbers (less than 50) of EVs in San Diego County. Because of this low rate of usage, some of our results were inconclusive.

The capability of the six charging stations in the Chargeport can provide over 120 charges per month, but the use of the CAC Chargeport by San Diego residents was disappointing. On the average, the Chargeport was used for only ten charges per month by one to three vehicles. The reason for this is the small number of EVs (less than 50) in San Diego.

The amount of energy generated by the PV system was about 4244 kWhrs for the nine month period of performance monitoring. The total energy used by EVs was 751 kWhr during the same period of time. The difference of nearly 3,500 kWhr was delivered to the electric grid. The peak output was measured at 3.5 kW, which is about half of the power (work) required to charge an EV and the system is only three percent efficient.

The economics of the Chargeport was disappointing. In order to use this technology to support the required infrastructure to meet CARB's goal of zero emission vehicles in California by 2003, the cost of the Chargeport technology would have to be reduced by at least 50 percent beginning in 2000. This is unlikely to happen.

The primary anticipated benefit from this technology is improved air quality. A second benefit would be economic development from the manufacture and construction of Chargeports if they were manufactured in the state.

The overall cost and space requirements of the Chargeport were the primary issues leading to abandoning a second host site. With the data from and the availability of the demonstration facility at the CAC, other potential hosts may change their perspective on hosting additional systems. The system costs will remain a mayor roadblock.

2.7 Economic Analysis

The total cost of the demonstration Chargeport was $175,000 including nearly $70,000 of project management, data acquisition and analysis, reporting, and site selection. The cost of $105,000 would be amortized over 20 years for a similar project. Using conventional present value amortization calculations and assuming an eight percent interest rate and zero inflation rates, the present value annual revenue requirements would be $22,500.

The typical annual operation and maintenance cost would be the labor cost of a maintenance visit to the Chargeport site once a quarter (estimated at $125 per visit or $500 per year).

The total present value revenue requirement would be about $27,500 (without discounting the O&M costs).

The typical energy generated by the Chargeport from PVs is nearly 500 kWh per month or 6,000 kWh per year. The present value cost of energy would be $27,500 per 6,000 kWh or about $4.58 / kWhr. This value is nearly two orders of magnitude higher than the cost of energy from the utility grid.

If we take the estimated cost of energy from the utility grid to charge EVs at $0.06 per kWhr, the monthly expected revenue would be $390 per month. At an eight percent interest rate for 20 years, the capital cost allotted for this type of investment would be about $ 47,000 or nearly 50 percent less than the cost for the demonstration Chargeport.

It is difficult to justify the high initial capital costs for the PV Chargeport in implementing this technology as part of the infrastructure required for promoting and supporting EVs in the 2003 time frame.

2.7.1 Commercialization Potential

The commercialization of any technology is based on cost and market potential. The near-term market potential for PV Chargeports is based on CARB's goal of 10 percent of all California new vehicles sold in 2003 meet the zero emission requirement. Assuming 200,000 are the total annual new vehicles sold in California, the total number of EVs sold in 2003 would be 20,000.

If 30 percent of those EVs were sold in San Diego County, then, beginning in 2003, nearly 6,000 EVs would be sold there annually. This could potentially serve as the basis for developing a charging infrastructure. It would not be unreasonable to install about 1,000 chargeports in San Diego County similar to this demonstration (six charging stations per chargeport). This would make the infrastructure visible to the public thereby promoting EV sales and allowing future growth.

Each Chargeport would have to cost no more than $ 47,000 including profit, installation and materials. Cost is based on the data from this demonstration. The average EV charge is six kW for six hours per charge station (Appendix I). This equates to 6,500 kWh per month. The cost of operation and maintenance is estimated at a nominal $500 per year.

At an average rate of $ 0.06 per kWh the monthly expected revenue would be $ 390 per month. An eight percent interest rate for 20 years was used in deriving the $ 47,000 cost of the Chargeport, which is about 50 percent of the cost for the demonstration Chargeport.

The potential markets for a product similar to the demonstration Chargeport, are approximately 300 units per year to meet the 2003 zero emissions vehicle goal. This equates to a total capital investment of nearly $14 million per year. The cost reduction of nearly 50 percent from the cost of the demonstration Chargeport, however, is a significant challenge to achieve in that timeframe.

The total cost for the demonstration project was $175,000 including $35,000 for the PV system, $40,000 for the EV chargers, $30,000 for construction, and $15,000 for performance data monitoring and reporting. This implies that the PV system and installation costs alone must be reduced by 50 percent in the year 2000.

2.7.2 Benefits to California

According to the CARB Electric Vehicle fact sheet 1998, nearly 90 percent of Californians live in areas that do not meet health air standards set by Federal and State governments. The primary benefit to California from PV/EV technology is an improvement in air quality by reducing emissions from power generation and motor vehicles.

In California, coal, gas, and oil account for 60 percent of the fuels used in power generation. Emissions of Nitrogen Oxides (NO_x) and Carbon Oxides (CO_x) are a direct result of burning these fuels. Average power production per kilowatt-hour produces an emission rate of 1.10 pounds of CO_x and 0.0001 pounds of NO_x.

The U.S. Department of Energy estimates a standard 5 kW rated PV system can avoid emissions of 11,300 pounds of CO_x and 1.02 pounds of NO_x per year. These values derived from averaging the PV efficiency, capacity factors, and energy production of a typical 5 kW grid supported by PV systems.

To approximate carbon emissions (airborne carbon) prevented, the CO_2 value (calculated above) is multiplied by 0.3. This equals 3,390 lbs. of carbon emissions prevented annually by the 5.0 kW system alone.

Motor vehicles consume half the oil in the U.S. and produce approximately half the urban pollution and one-fourth of the greenhouse gases. Although there has been significant progress since 1970 in reducing emissions per mile traveled in combustion engine motor vehicles, the number of cars and the miles traveled have doubled during the same time. In 1990, the CARB recognized that even the cleanest gasoline-powered vehicles couldn’t reduce pollution enough to satisfy the State’s clean air goals.

The need for zero emission vehicles, such as EVs, is critical. Demonstrating and publicizing PV/EV technology will support development of a Chargeport infrastructure and encourage the purchase and use of EVs.

Table 2 lists the annual emissions and fuel consumption for the average passenger vehicle in the U.S.

Table 2. Annual Emissions & Fuel Consumption

Pollutant Problem	Amount	Miles	Pollution or Fuel Consumption
Hydrocarbons Urban ozone (smog) and Air Toxics	2.9 grams/mile	12,500	80 lbs. of HC
Carbon Monoxide Poisonous gas	22 grams/mile	12,500	606 lbs. of CO
Nitrogen Oxides (smog)and Acid Rain	1.5 grams/mile	12,500	41 lbs. of NOx
Carbon Dioxide Global warming	0.8 pound/mile	12,500	10,000 lbs. of CO2
Gasoline Imported oil	0.04 gallon/mile	12,500	550 gallons gasoline

**All values taken as averages. Emission factors used standard EPA emission models. An average, properly maintained car or truck on the road in 1997, operating on typical gasoline on a summer day (72ºF to 96ºF). U.S. Environmental Protection Agency National Vehicle and Fuel Emissions Laboratory EPA420-F-97-037

3.0 Conclusions and Recommendations

If a facility such as the CAC with a large parking area installed a covered parking structure that used PVs as the roofing material and provided an EV charging stations, the excess energy could be delivered to the electric grid during electric-peak demand periods. A PV system supporting an electric distribution system would have to be much larger that the Chargeport to impact a circuit that is nominally rated at 12,000 Volts and carries a capacity of 8,000 kW to 10,000 kW.

3.1 Conclusions

- For the PV system and Chargeport components to be competitive in the market place, initial costs must be reduced by more than 50 percent.
- Potentially, an infrastructure of 1,000 Chargeports could reduce airborne carbon emissions by nearly 3.4 million pounds a year.
- With limited subsidy from solar technology programs, the initial cost of the Chargeport components could be substantially reduced to make the technology affordable.

3.1.1 Recommendations

It would be beneficial to the PV and EV industries, the PIER Program, and environmental agencies to support the continued demonstration of the Chargeport and potentially fund a second demonstration with a new host.

To continue promoting the use of EVs and environmentally clean energy generation technology, such as PVs:

- The Chargeport should continue its operation.
- Establish cost targets that would make the PV/EV concept economically viable.

4.0 Glossary

Air Monitoring	Sampling for and measuring of pollutants present in the atmosphere.
Air Pollutants	Amounts of foreign and / or natural substances occurring in the atmosphere that may result in adverse effects to humans, animals, vegetation, and / or materials.
Air Pollution	Degradation of air quality resulting from unwanted chemicals or other materials occurring in the air.
Air Toxics	A generic term referring to a harmful chemical or group of chemicals in the air. Substances that are especially harmful to health, such as those considered under U.S. EPA's hazardous air pollutant program or California's AB 1807 toxic air contaminant program, are considered to be air toxics. Technically, any compound that is in the air and has the potential to produce adverse health effects is an air toxic.
Availability	Information of operational effectiveness of the system. Calculated based on each 15-minute interval in which energy was measured and defined as the hours of operation in a day divided by the available hours in a day.
California Air Resources Board (CARB)	The State's lead air quality agency consisting of an 11-member Governor-appointed board. CARB is responsible for attainment and maintenance of the state and federal air quality standards, and is fully responsible for motor vehicle pollution control. It oversees county and regional air pollution management programs.
Carbon Dioxide (CO_2)	A colorless, odorless gas that occurs naturally in the earth's atmosphere. Significant quantities are also emitted into the air by fossil fuel combustion. Emissions of CO_2 have been implicated with increasing the greenhouse effect, and contributing to global warming.

Carbon Monoxide (CO)	A colorless, odorless gas resulting from the incomplete combustion of hydrocarbon fuels. CO interferes with the blood's ability to carry oxygen to the body's tissues and results in numerous adverse health effects. Over 80 percent of the CO emitted in urban areas is contributed by motor vehicles. CO is a criteria air pollutant.
Carcinogen	A cancer-causing substance.
Capacity Factor	Measure of effectiveness calculated by taking the measured energy per day and dividing by the rated value. The capacity factor provides information on the performance of the system compared to a baseline.
DAS	Data Acquisition System (DAS) provides monitoring of the PV performance and EV consumption via telecommunication lines.
Electric Vehicle (EV)	A motor vehicle that uses an electric motor as the basis of its operation. Such vehicles emit virtually no air pollutants.
Emission Factor	The relationship between the amount of pollution produced and the amount of raw material processed or burned. For example, the emission factor for oxides of nitrogen from fuel oil combustion in an industrial boiler would be the number of pounds of oxides of nitrogen emitted per 1000 gallons of fuel burned. By using the emission factor of a pollutant and specific data regarding quantities of materials used by a given source, it is possible to compute emissions for the source. This approach is used in preparing an emissions inventory.
Hydrocarbons	Compounds containing various combinations of hydrogen and carbon atoms. They may be emitted into the air as a result of fossil and vegetative fuel combustion, fuel volatilization, solvent use, and are a major contributor to smog.
Monitoring	The periodic or continuous sampling and analysis of air pollutants in ambient air or from individual pollution sources.

Nitrogen Oxides (Oxides of Nitrogen, NOx)	A general term pertaining to compounds of nitric oxide (NO), nitrogen dioxide (NO_2), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion processes, and are major contributors to smog formation and acid deposition. NO_2 is a criteria air pollutant, and may result in numerous adverse health effects.
Ozone (O_3)	A strong smelling, pale blue reactive toxic chemical gas consisting of three oxygen atoms. It is a product of the photochemical process involving the sun's energy and ozone precursors, such as hydrocarbons and oxides of nitrogen. Ozone exits in the upper atmosphere ozone layer (stratrospheric ozone) as well as at the earth's surface (tropospheric ozone). Tropospheric ozone causes numerous adverse health effects and is a criteria air pollutant. Tropospheric ozone is a major component of smog.
Ozone Depletion	The destruction of the stratospheric ozone layer, which shields the earth from ultraviolet radiation. This destruction is caused by the breakdown of certain chlorine and / or bromine-containing compounds that catalytically destroy ozone molecules in the stratosphere.
Smog	A combination of smoke, ozone, hydrocarbons, nitrogen oxides, and other chemically reactive compounds which, under certain conditions of weather and sunlight, may result in a murky brown haze that causes adverse health effects. The primary source of smog in California is motor vehicles.
System Efficiency	The losses in converting solar irradiance to electrical power.
U.S. Environmental Protection Agency (U.S. EPA)	The United States agency charged with setting policy and guidelines, and carrying out legal mandates for the protection of national interests in environmental resources.
Zero Emission Vehicle (ZEV)	Vehicles which produce no emissions from an on-board source of power (e.g., an electric vehicle).

Appendix I

Paragon Performance Monitoring and Analysis Report

Appendix I

PARAGON PERFORMANCE MONITORING AND ANALYSIS REPORT

Electric Vehicle Solar Chargeport Project

Final Report for Data Acquisition Results

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Notifications

This project report was prepared under San Diego Gas & Electric (SDG&E) Purchase Order C9811 20152, issued to Paragon Consulting Services on 11/12/98.

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1.0 Introduction

SDG&E has integrated photovoltaic (PV) technology with Electric Vehicle (EV) charging stations in order to serve the San Diego community with an environmentally-friendly energy solution. The proliferation of EV utilization requires accessible, conveniently-located charging stations. Integrating PVs into EV charging stations provides on-site power generation that alleviates the electric demand during peak hours of the day. Also, the PV system is grid connected, in order to make use of excess generation by feeding it into the utility grid.

In order to demonstrate the effectiveness of an EV Solar Chargeport, SDG&E constructed a 5 kilowatt PV array that provides power to 6 EV charging stations. This system was constructed in the parking lot of the County Administration Building, and therefore provides county employees a place to charge their EVs during work hours.

As part of the field test, a Data Acquisition System (DAS) was installed to monitor the performance characteristics of the PV power production and the EV energy consumption. System data collection began in November 1998 and continued through July 1999. These results are presented in this report.

2.0 System Description

The following section provides a description of the system.

2.1 Electric Vehicle Solar Chargeport

The structure is located in San Diego, California, on the corner of Grape Street and Pacific Highway at the parking lot of the County Administration Building. It is situated near the San Diego International Airport and near the ocean, which typically provides cooler temperatures and a mild breeze.

The Solar Chargeport has been constructed to provide both conductive and inductive charging stations. Three conductive and three inductive EV chargers are installed underneath the PV structure to allow easy access to vehicle charging interfaces. The system is grid-connected, and the excess energy produced is fed back into the utility grid.

The Solar Chargeport consists of 42 United Solar Systems SSR-120 photovoltaic modules, generating 5,040 watts (rated at standard test conditions). One Trace inverter (SW5548) provides 240 VAC, 60 Hz power output from the DC input. The following block diagram shows the components of the EV Solar Chargeport.

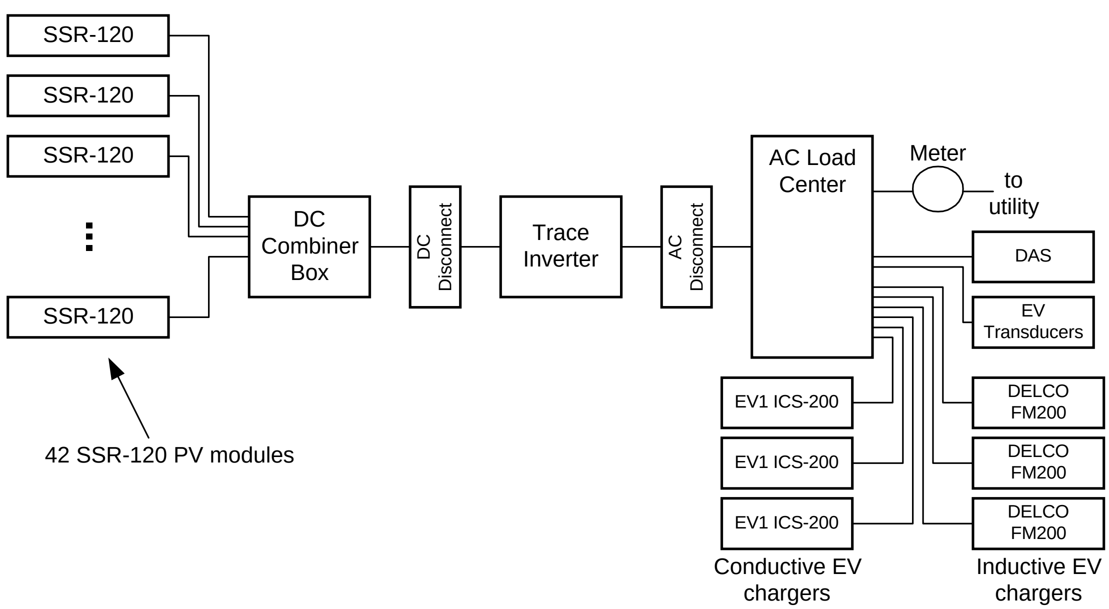

Figure 1. EV Solar Chargeport Block Diagram

2.2 Data Acquisition System

The Data Acquisition System (DAS) provides monitoring of PV performance and EV consumption. It enables SDG&E to profile the energy patterns of the system in 15-minute intervals. In addition to electrical parameters, environmental sensors are used to capture environmental data to help identify the effects of climate on the PV array. Table 1 lists the data parameters collected by the DAS.

Table 1. DAS Data Parameters

Data Parameter	Measurement Units	Measurement Device
PV Output Power	Watts	Watt/Watt-hour transducer
PV Output Energy	Watt-hours	Watt/Watt-hour transducer
Solar Irradiance	Watts per meter^2	Pyranometer
Ambient Temperature	^{o}Celsius	Thermocouple
Cell Temperature	^{o}Celsius	Thermocouple
EV Power Consumed	Watts	Watt transducer (1 per EV charger)

In addition to the sensors listed in the table, the DAS consisted of the following:

- Campbell Scientific CR10X datalogger
- Campbell Scientific telephone modem
- +12VDC, 600mA linear power supply
- Campbell Scientific 16-channel multiplexer (to accommodate additional signals from EV charger transducers)
- Enclosures for the datalogger and the EV charger power transducers

Data was collected remotely via the telephone modem. Each night, a server initiated a communications session with the DAS, collected new data and synchronized the clock. A dedicated phone line at the site was used for data collection purposes.

Each 15-minute data packet is timestamped. Table 2 shows a sample excerpt from the collected data. As the table shows, EV charger 3 was being used at this time.

Table 2. Sample Data Packets

Date/Time	Panel Temp (^{o}F)	Ambient Temp (^{o}F)	Solar Irrad. (W/m^2)	Power (kW)	Energy (kWh)	EV1 (kW)	EV2 (kW)	EV3 (kW)	EV4 (kW)	EV5 (kW)	EV6 (kW)
07/29/99 01:30 PM	85.316	76.784	915	2.725	0.673	0.013	0.019	4.907	0.012	0.01	0.012
07/29/99 01:45 PM	85.298	77.036	909	2.699	0.6697	0.013	0.019	4.892	0.012	0.009	0.012

3.0 Summary of Results

The following sections provide a summary of the field test results based on the collected data.

3.1 Energy Production

The EV Solar Chargeport produced a total of 4,244.3 kWh during the nine months data was collected. The line in the following chart shows that the average monthly energy production was 471.6 kWh. In the summer months, the increased sunlight hours and the greater levels of solar irradiance are the reasons for the corresponding increase in energy production.

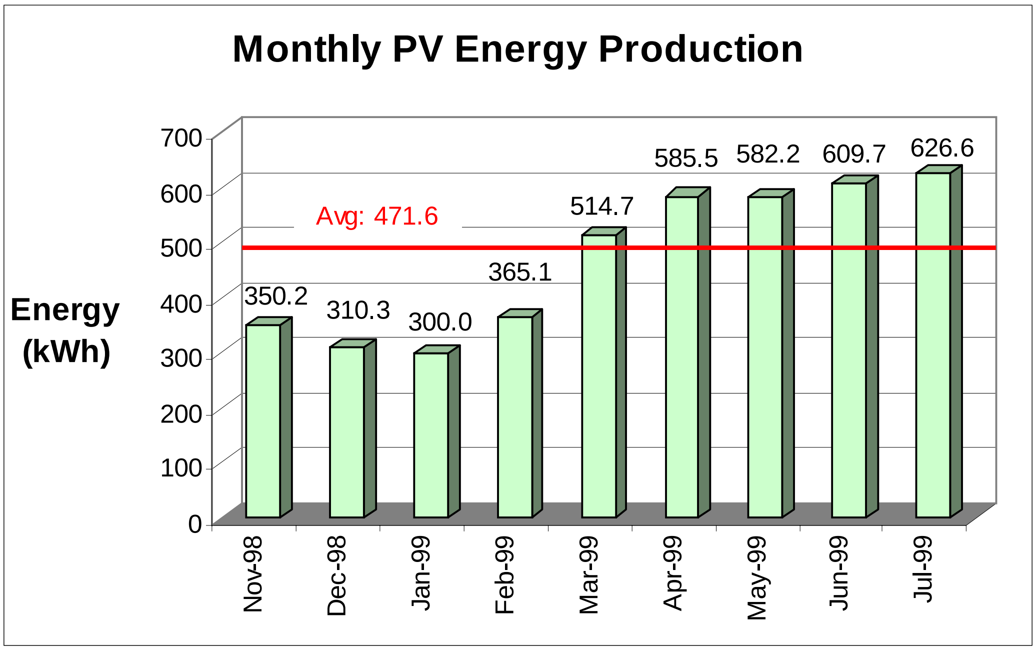

Figure 2. Monthly PV Energy Production

In each month's report, a daily energy chart was included to show how the system performed each day of the month. In Figure 3, a comparison between a winter month (January 1999) and a summer month (July 1999) shows that there are a greater daily totals in the summer month.

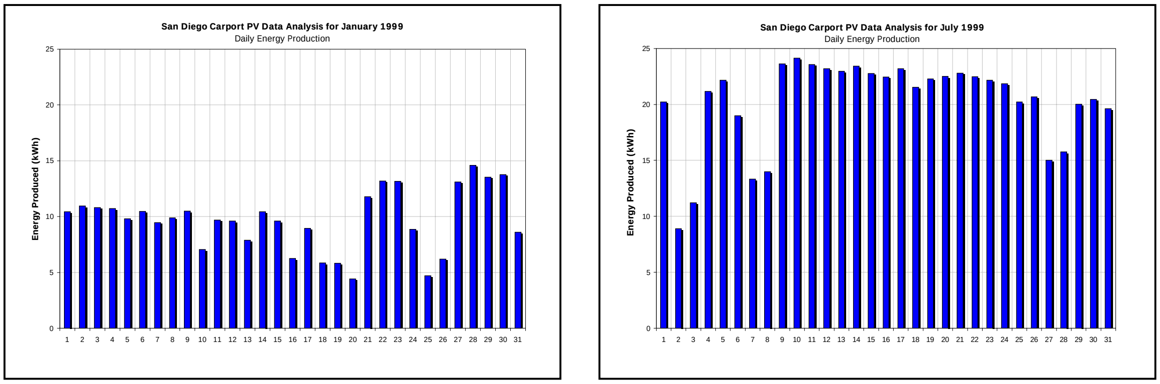

Figure 3. Energy Production: Winter Month vs. Summer Month

3.2 Daily Power Profiles

Daily power profiles provide insight into each day of operation. These profiles help determine whether the day was generally sunny or cloudy by the pattern of power generation compared to the solar irradiance measured. The following charts show the difference between a sunny day with high solar irradiance, and a cloudy day with lower solar irradiance levels.

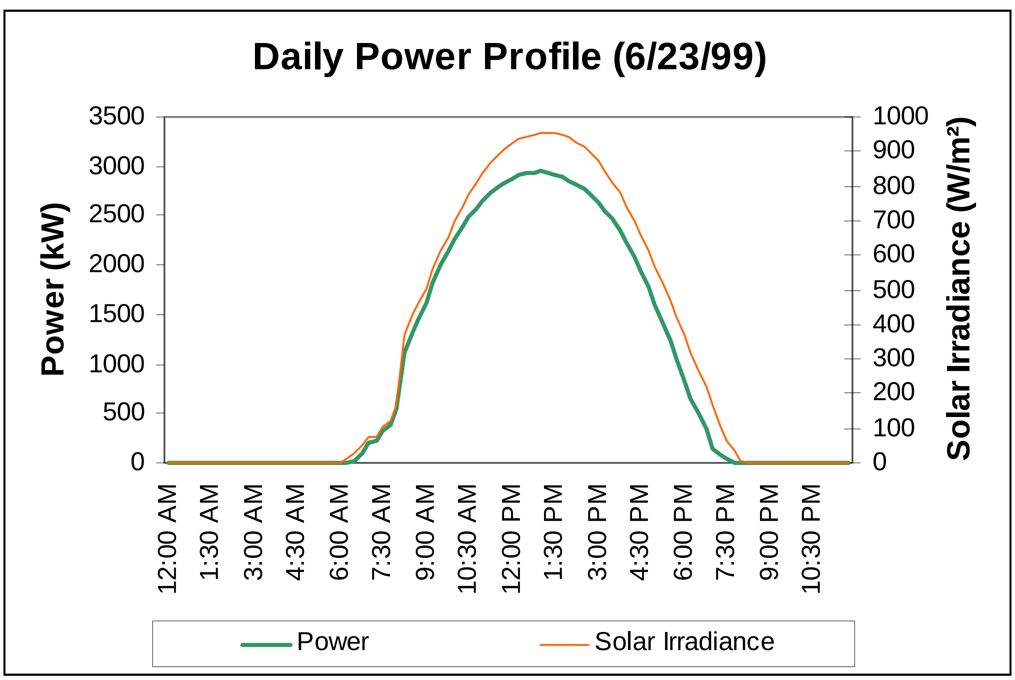

Figure 4. Daily Power Profile - Sunny Day (6/23/99)

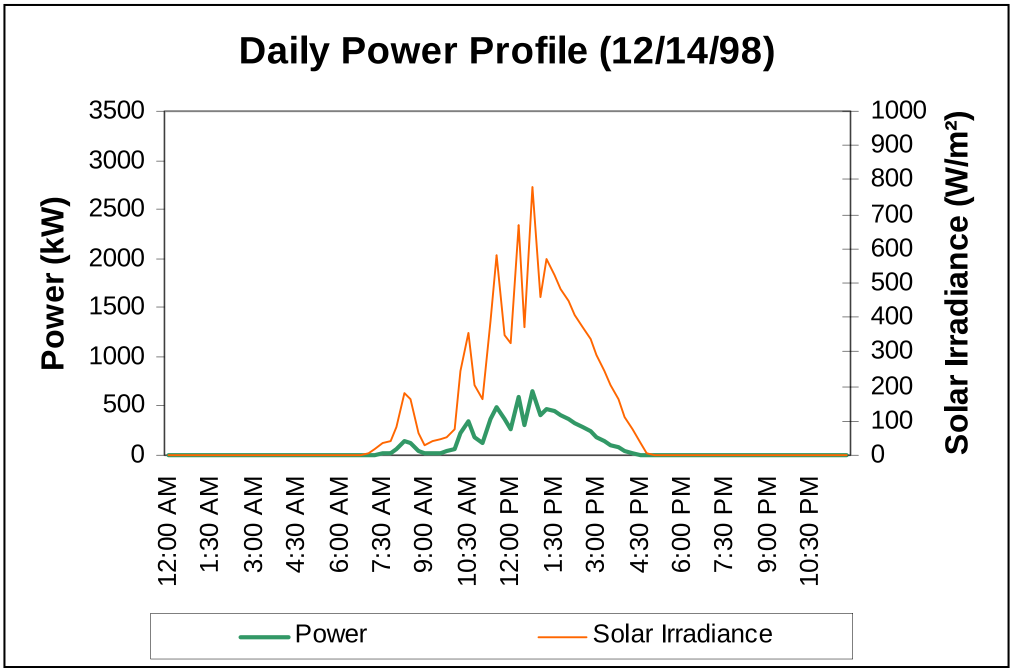

Figure 5. Daily Power Profile - Cloudy Day (12/14/99)

From Figure 4, the smooth, bell-shaped curve is representative of a sunny day. The peak is reached in the afternoon, at about 1:00pm. In Figure 5, the power production levels are significantly lower than in Figure 4. The cloudy day shows jagged lines representative of inconsistent solar irradiance values. In both cases, the power output curves follow the solar irradiance curves.

In order to provide a monthly view of the daily power produced, two charts were used. Figure 6 shows the peak values for each day of the month for power and solar irradiance. Figure 7 shows daily thumbnails of power production for a month. These two charts were included in each month's report, and provided a detailed view to point out any maintenance issues that would require servicing. For example, if a daily thumbnail curve ended abruptly, or if a power peak value did not track with the solar irradiance peak value, there could be a problem with the system. There were no such incidents in the nine months this EV Solar Chargeport was monitored.

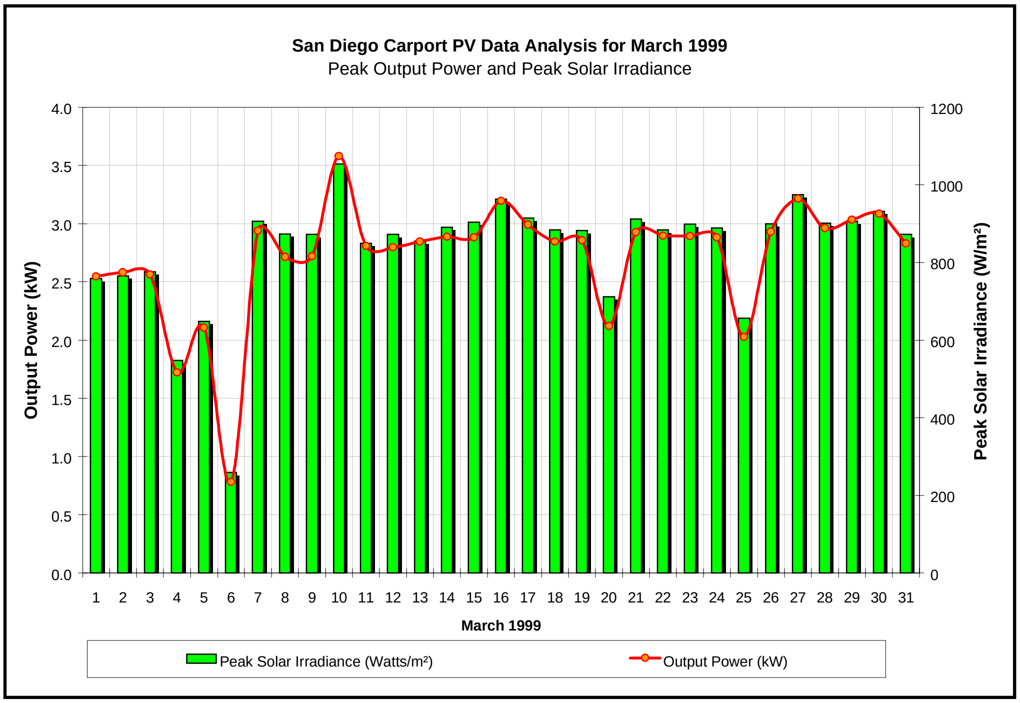

Figure 6. Peak Output Power and Peak Solar Irradiance - March 1999

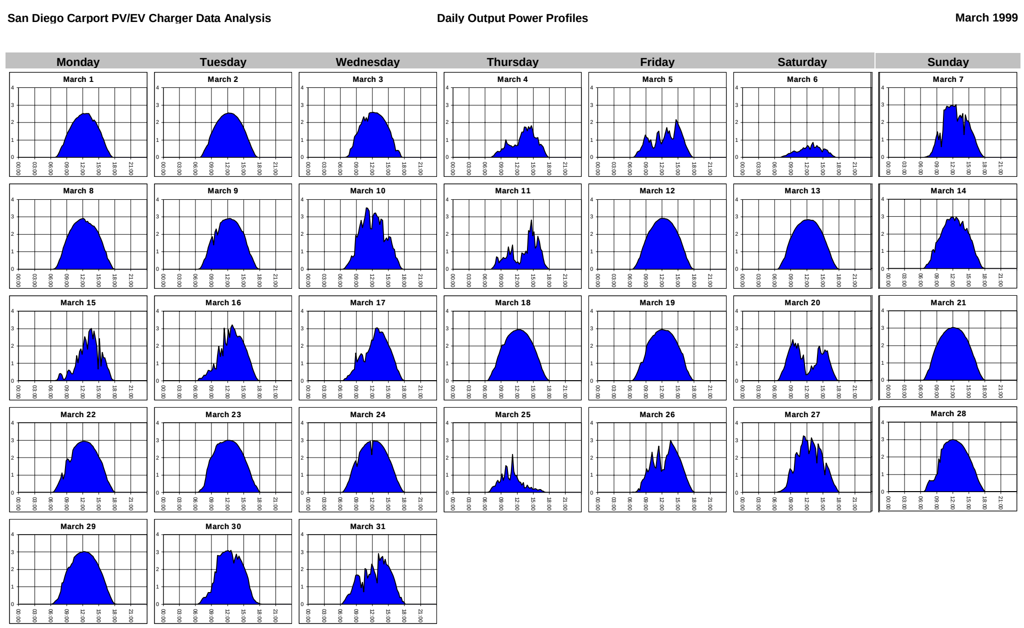

Figure 7. Daily Power Thumbnails - March 1999

3.3 EV Usage

Energy usage for the monitoring period was 750.7 kWh (an average of 83.4 kWh/month). As the following chart shows, the peak month was April 1999.

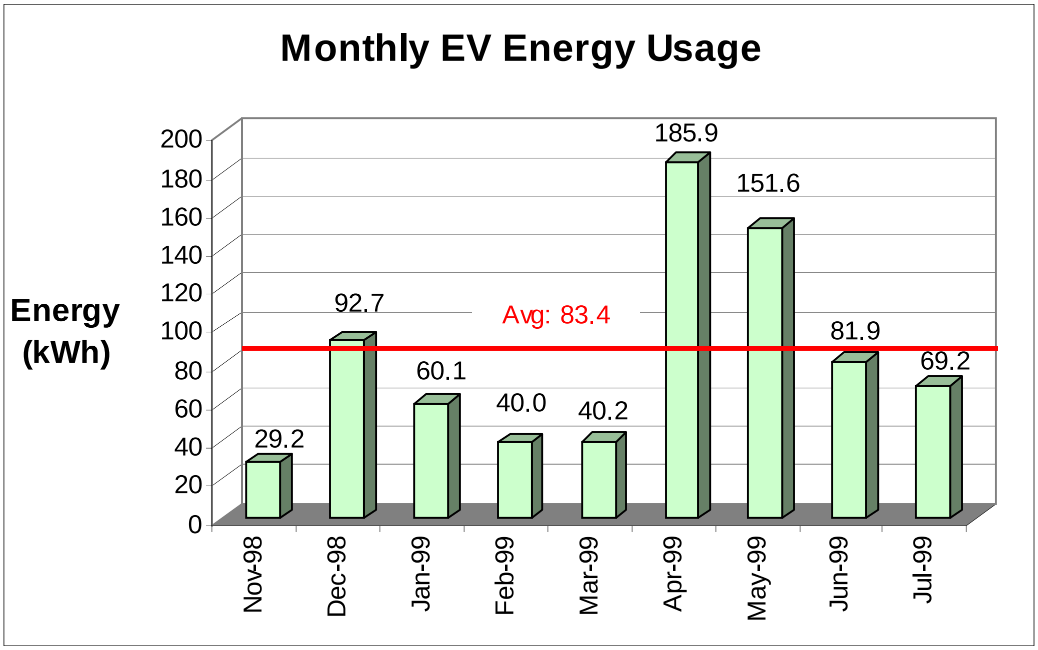

Figure 8. Monthly EV Charger Usage

In order to provide a more detailed view of the EV power and energy requirements, two charts were generated each month. The first chart (Figure 9) is a thumbnail view of energy consumption each day of the month. This chart shows when and how long an EV charger was in use. It also picks up patterns of usage - for example, Figure 9 shows that the same EV charging station was used on Tuesday and Thursday the first full week of the month, but then the pattern changed to Mondays and Wednesdays the remainder of the month.

The second chart (Figure 10) shows the demand requirements of the EV chargers. This chart shows the demand levels required by the charging stations. Since the peak output of the PV system has been measured at about 3.5 kW, and the EV charger demand is generally between 5 and 7 kW, the utility must provide for the difference.

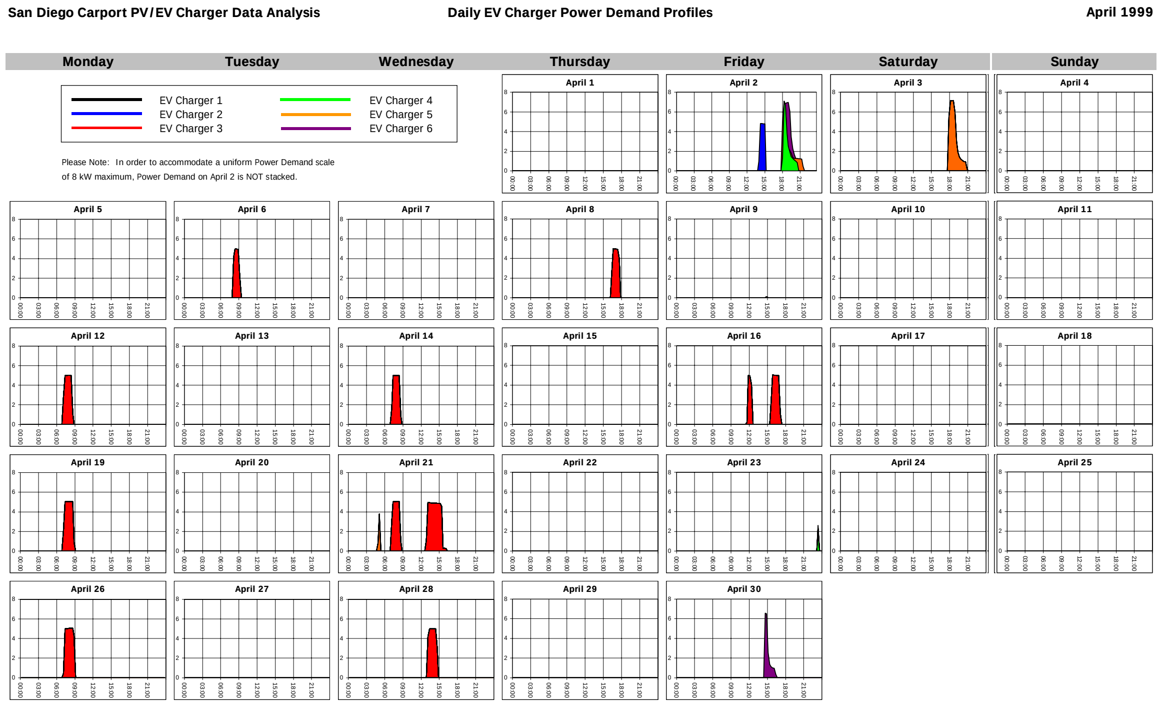

Figure 9. EV Daily Energy Consumption Thumbnails - April 1999

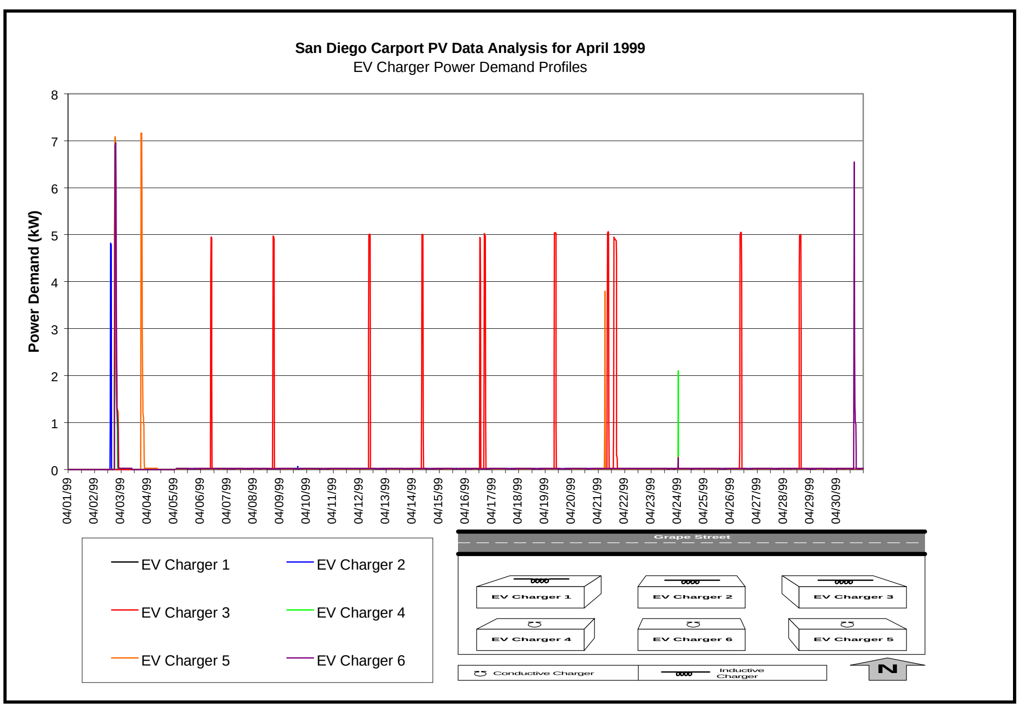

Figure 10. EV Charger Demand Profile - April 1999

3.4 Solar Irradiance Effects

The pyranometer used in the DAS measures plane-of-array (POA) irradiance, which includes both direct normal (direct sunlight) and diffuse (light reflected off of clouds, etc.). A LI-COR pyranometer was used to measure solar irradiance in watts per square meter units.

Solar irradiance directly affects the performance of the PV system's output power. This is exemplified in the following chart that plots output power vs. solar irradiance, for data in which solar irradiance is above 500 W/m^2. This value was chosen due to the non-linearity exhibited by data points under 500 W/m^2, which would alter the slope of the straight line drawn through the data points. In addition, 500 W/m^2 was selected by the Utility PhotoVoltaic Group (UPVG) as the reference threshold above which to evaluate the performance of PV systems.

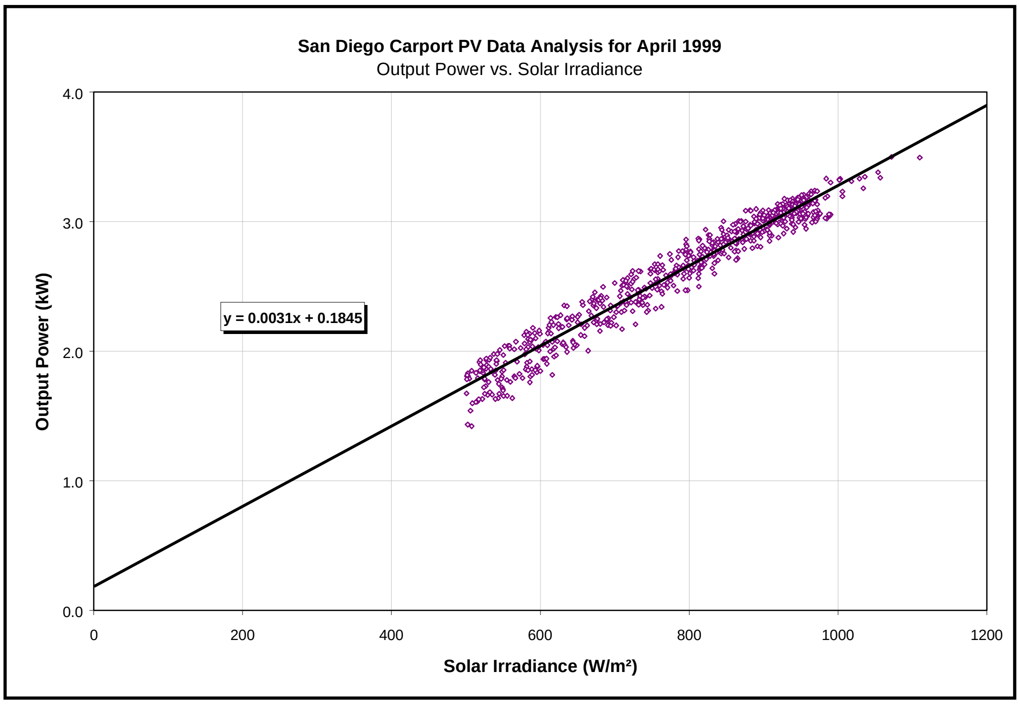

Figure 11. Output Power vs. Solar Irradiance - April 1999

3.5 Temperature Effects

Temperature has an inverse relationship to output power in PV arrays. The EV Solar Chargeport is installed in a cooler climate, are therefore the temperature effects are not as significant as in warmer regions. The following chart does show that the within a range of 50 W/m^2 solar irradiance (for the month of April 1999), increasing temperature results in decreased power output.

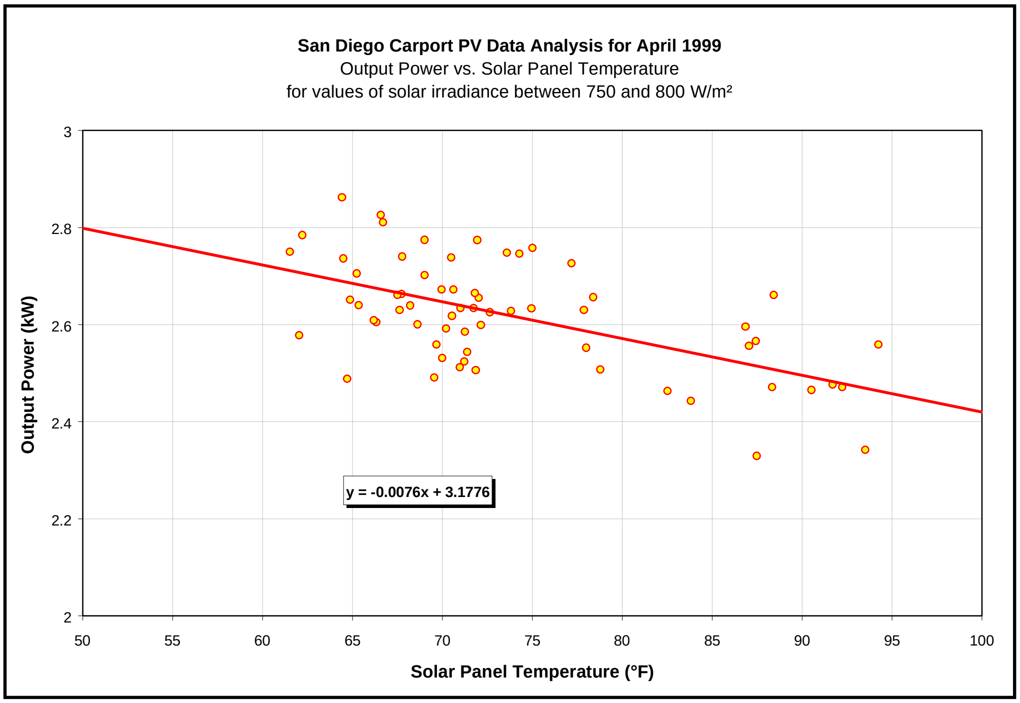

Figure 12. Output Power vs. Solar Panel Temperature - April 1999

3.6 System Efficiency

System efficiency takes into account all the losses in converting solar irradiance to electrical power, as well as the balance of system component losses. System efficiency is calculated as follows:

$$\text{Efficiency (\%)} = \text{Output Power (Watts)} / [\text{SI (W/m}^2\text{)} * \text{SA (m}^2\text{)}]$$

where SI is the solar irradiance measured, and SA is the surface area of the PV array. Each month, the system efficiency is plotted against the output power, and for all values in which SI > 500 W/m^2, an average monthly value is calculated. The monthly chart is shown in the following diagram.

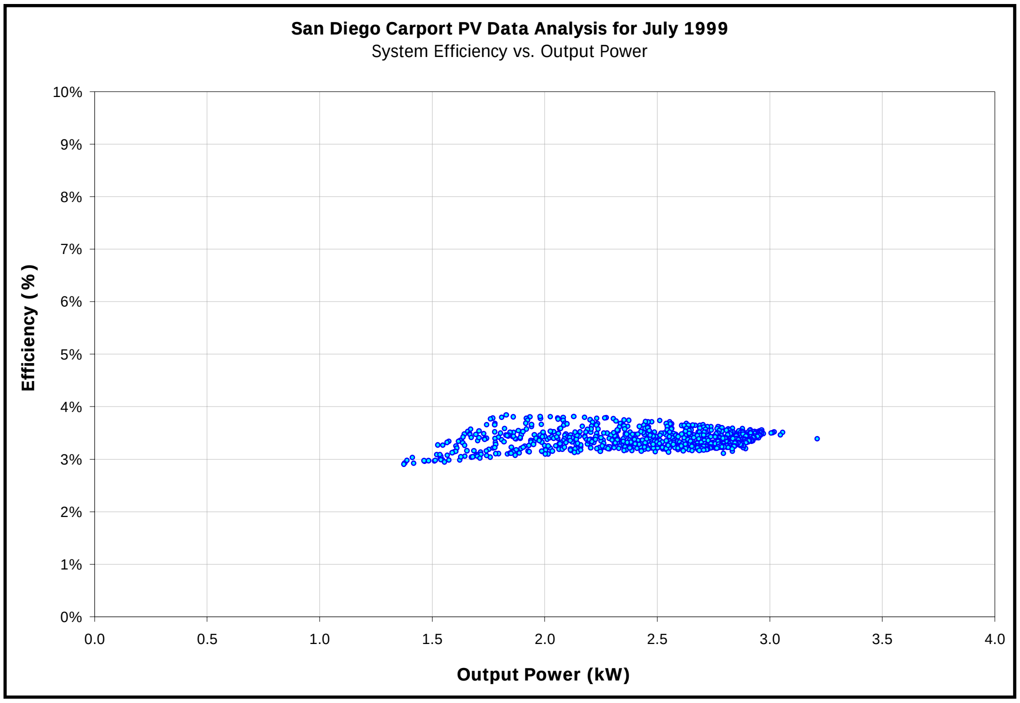

Figure 13. System Efficiency of PV Array - July 1999

For thin film PV products, this range between 3% and 4% is typical. Based on the data points from Figure 13, an average system efficiency value is calculated to be 3.37% for July 1999. These average efficiency values are plotted by month in the following chart. The trend shows that as the summer months bring slightly warmer temperature, the system efficiency decreases slightly. In addition to temperature, the soiling that builds up on the PV array has an effect on the efficiency of the system.

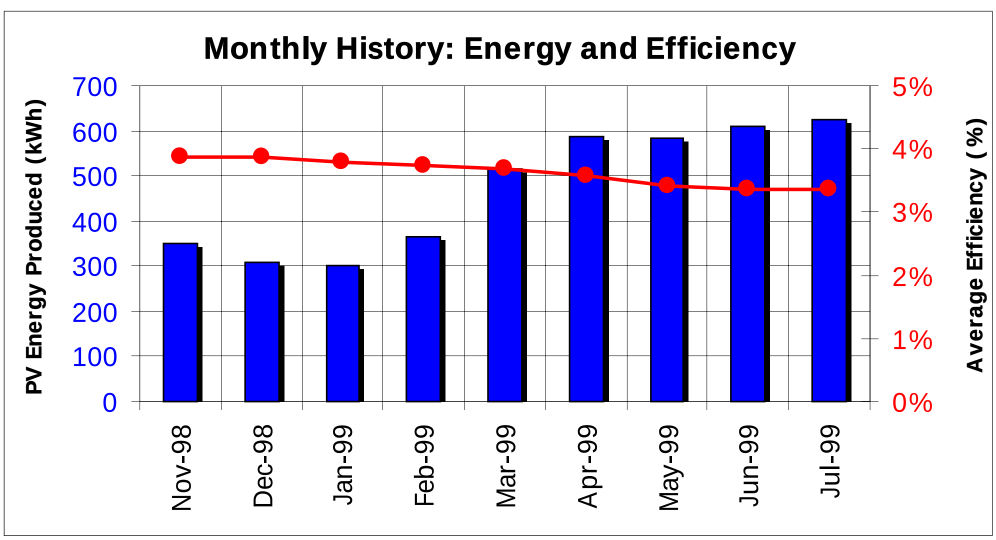

Figure 14. System Energy Production and Efficiency by Month

3.7 Availability

Availability of a PV system provides information on the operational effectiveness of the system. It is calculated based on each 15-minute interval in which energy was measured. Availability is defined as the hours of operation in a day divided by the available hours in a day. In other words, in a 24 hour period, how many hours did the PV system produce energy? Availability is calculated based on the following formula:

Availability = [Total Hours of Operation] / [Total Hours/Day]

In summer months with longer daylight hours, the availability is higher than in winter months. The following chart shows the average availability value by month since monitoring began.

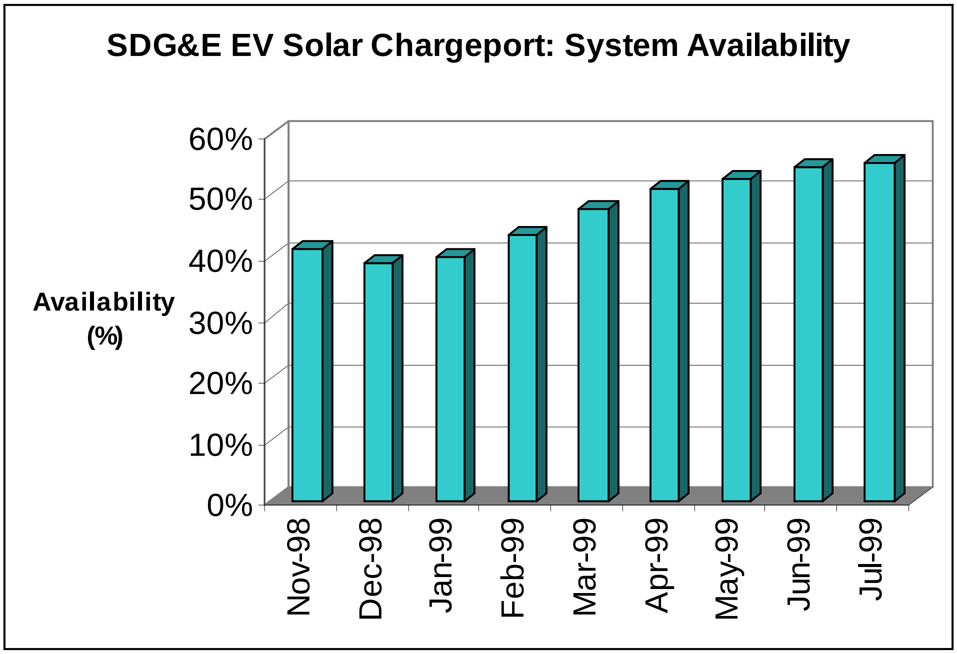

Figure 15. System Availability

Another measure of effectiveness is the capacity factor. The capacity factor of a system is calculated by taking the measured energy per day and dividing by the rated value.

Capacity Factor (CF) = [Total kWh/day (measured)] / [Rated kW * 24 hrs]

Whereas the availability of the system shows how many hours the system was operating, the capacity factor provides information on the performance of the system compared to a baseline (rated power = 5.040 kW multiplied by 24 hours). For each month, an average value was determined by averaging daily capacity factor. As the following chart shows, the month with the highest capacity factor was June 1999.

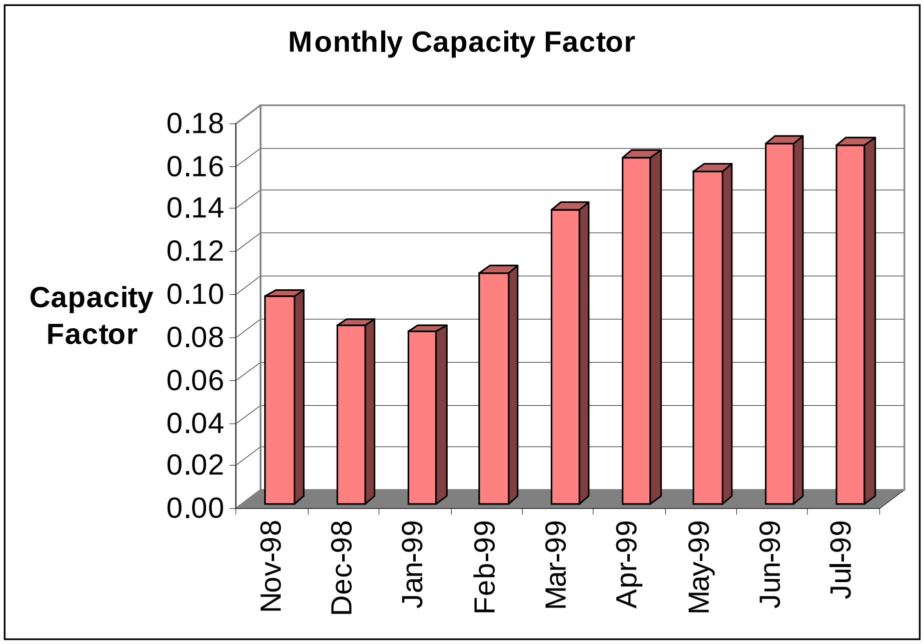

Figure 16. Capacity Factor

3.8 Balance of System Reliability

Balance of system reliability is a measure of uptime. Downtime occurs when maintenance requires the system to be shut off, or if a component fails and must be repaired or replaced. Since monitoring began in November 1998, the system has been operational 100%. The balance of system components have not yet required any maintenance actions that required the system to be shut down.

3.9 Communications Reliability and DAS Uptime

Relative to the telephone communications via analog modems, reliability has been 100% thus far. Communications is initiated once a day from Paragon's server to the DAS. Since the DAS modem is connected to a dedicated line, there were no issues with interference.

DAS uptime refers to the availability of the datalogger to collect and store data. Missing data packets, failure of the datalogger or power supply, loss of grid are some of the causes of decreased DAS uptime. Since November 1998, DAS uptime has been 100% (273 consecutive days of operation).

4.0 Conclusions

The EV Solar Chargeport has been a reliable installation that successfully integrated EV chargers with a grid-connected PV system. The system has operated reliably between November 1998 and July 1999, without any requirements for maintenance actions on any of the components. It has provided a charging station for users of EVs in the downtown San Diego area.

The data collected has provided SDG&E with insight into the daily operations of the system's PV system, as well as a record of EV charger utilization. The results quantified in this report show that the chargeport also provides an element of grid support to the local utility by generating power during the day, when the chargers are typically consuming energy. The overall system has been an effective demonstration of an EV Solar Chargeport.

Appendix 1: Monthly Data Charts

The following shows data charts for each month the EV Solar Chargeport was monitored.

November 1998

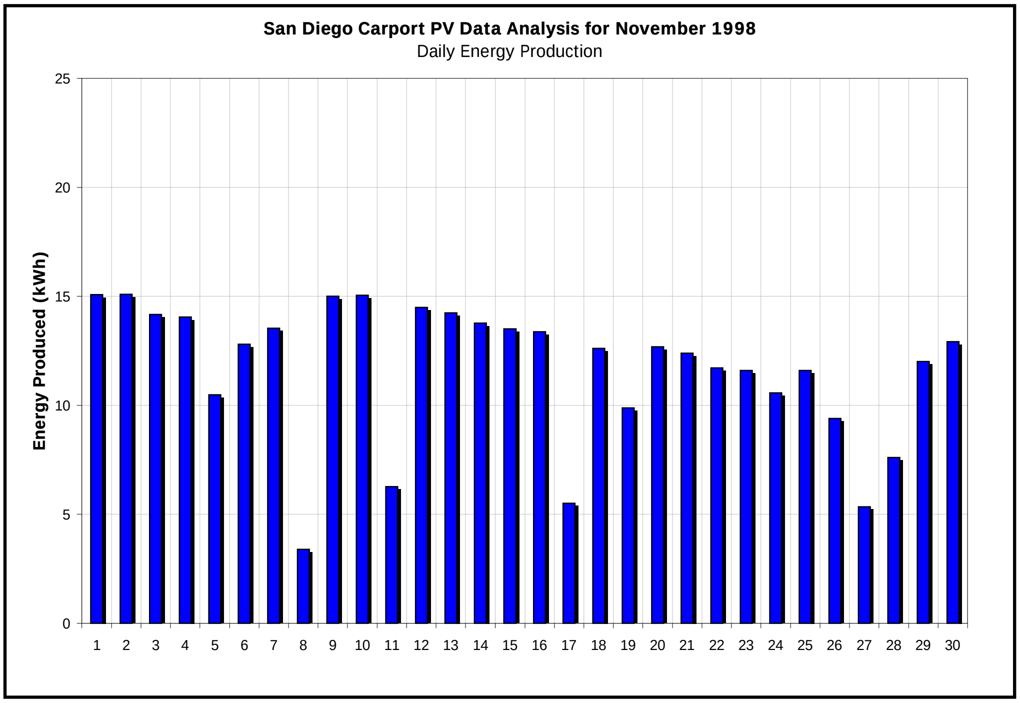

Figure A- 1. Daily Energy Production - November 1998

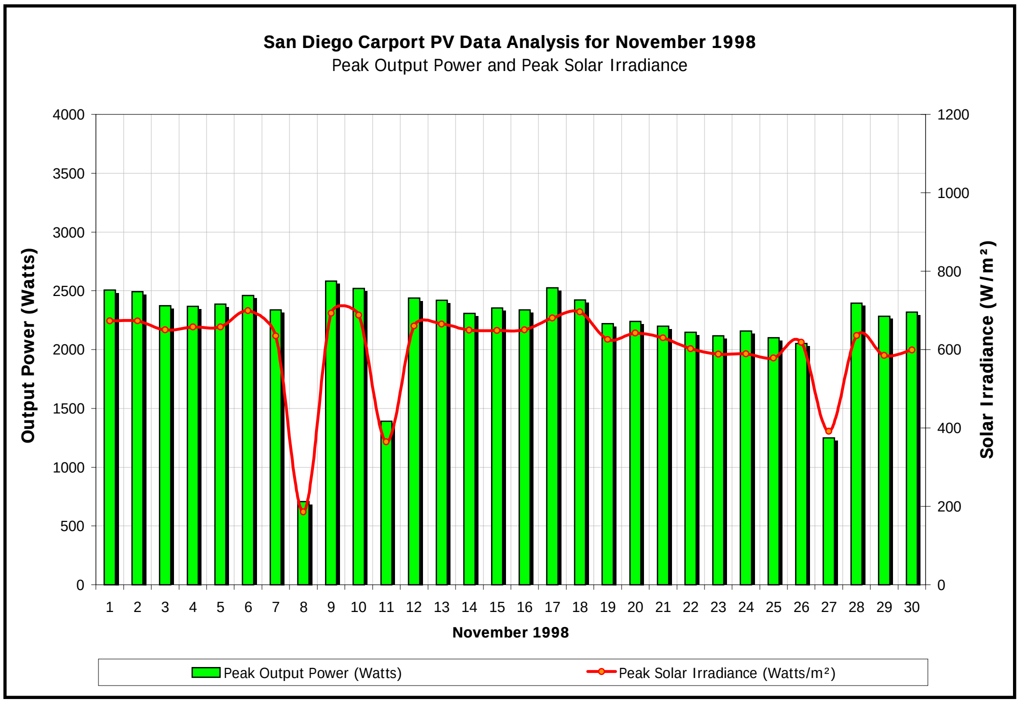

Figure A- 2. Peak Power and Peak Solar Irradiance - November 1998

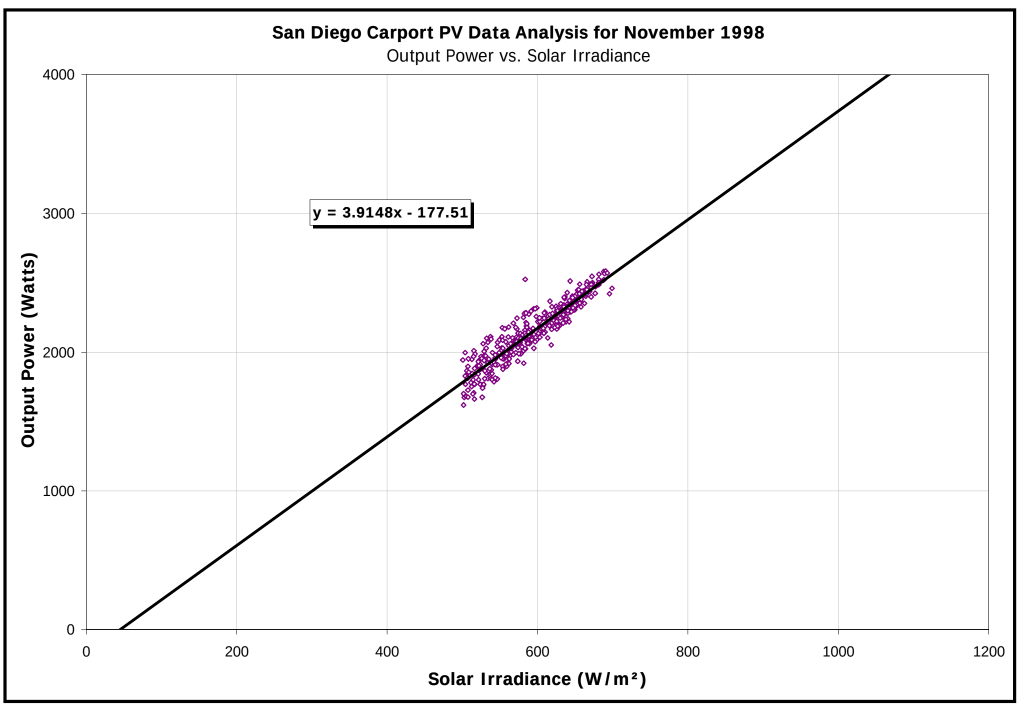

Figure A- 3. Output Power vs. Solar Irradiance - November 1998

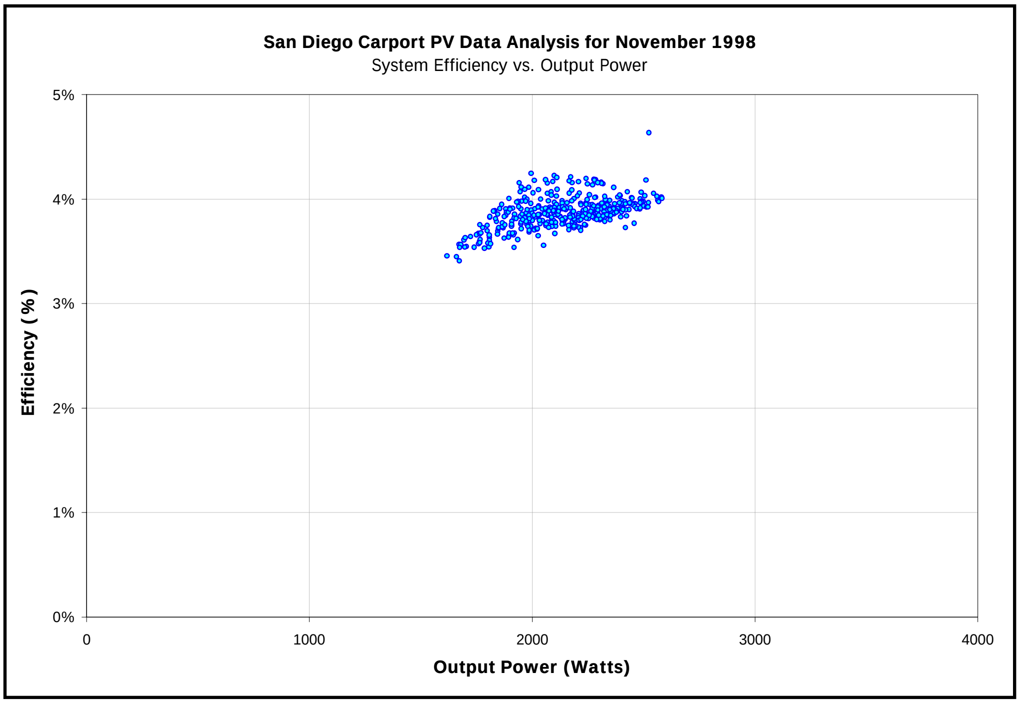

Figure A- 4. Efficiency vs. Output Power - November 1998

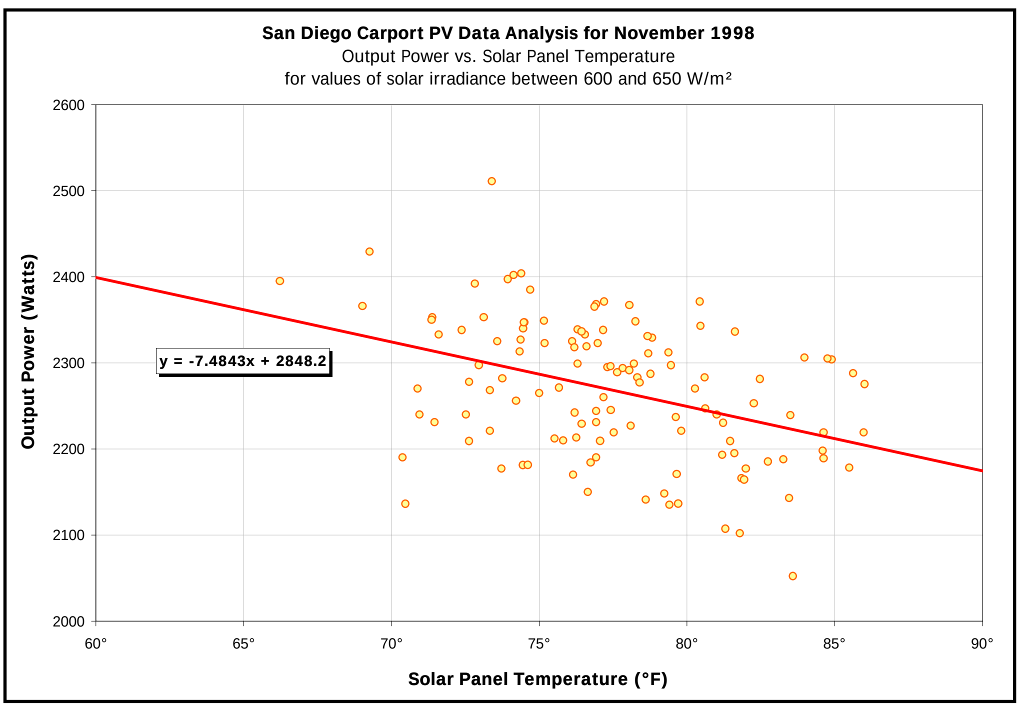

Figure A- 5. Output Power vs. Solar Panel Temperature - November 1998

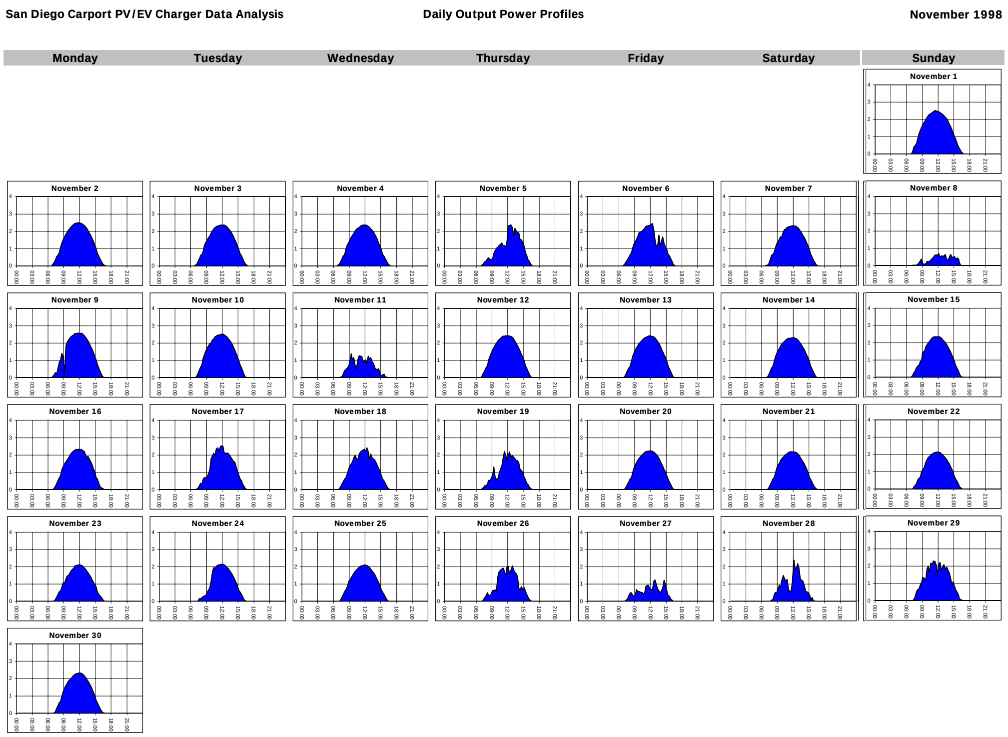

Figure A- 6. PV System Power Output Daily Thumbnails - November 1998

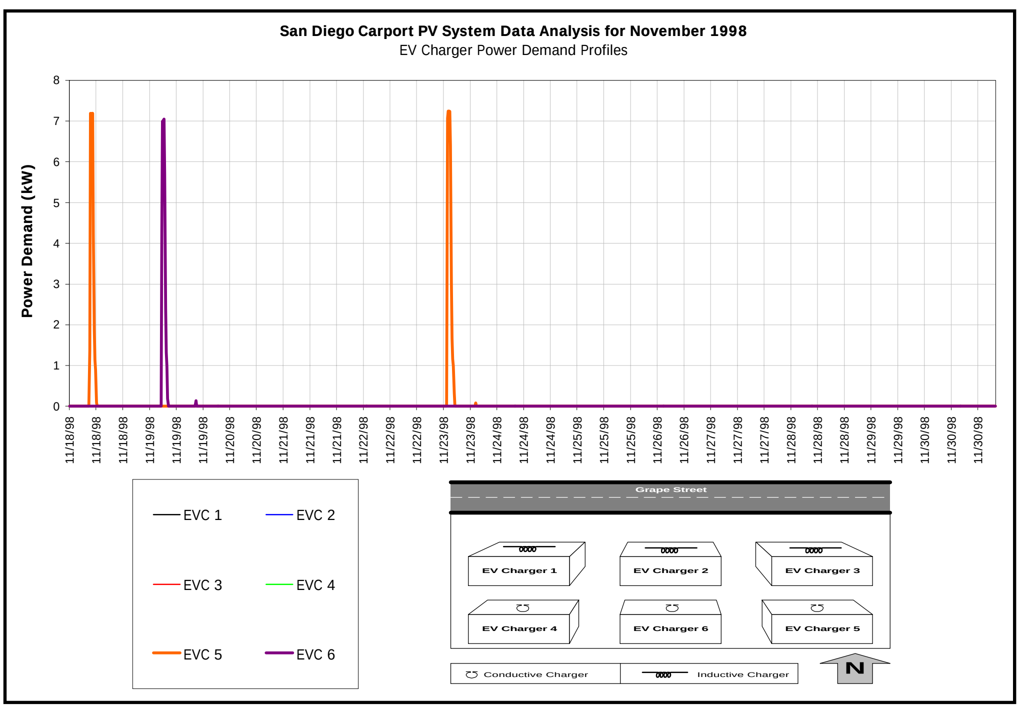

Figure A- 7. EV Charger Demand Profile - November 1998

Figure A- 8. EV Charger Usage Daily Thumbnails - November 1998

December 1998

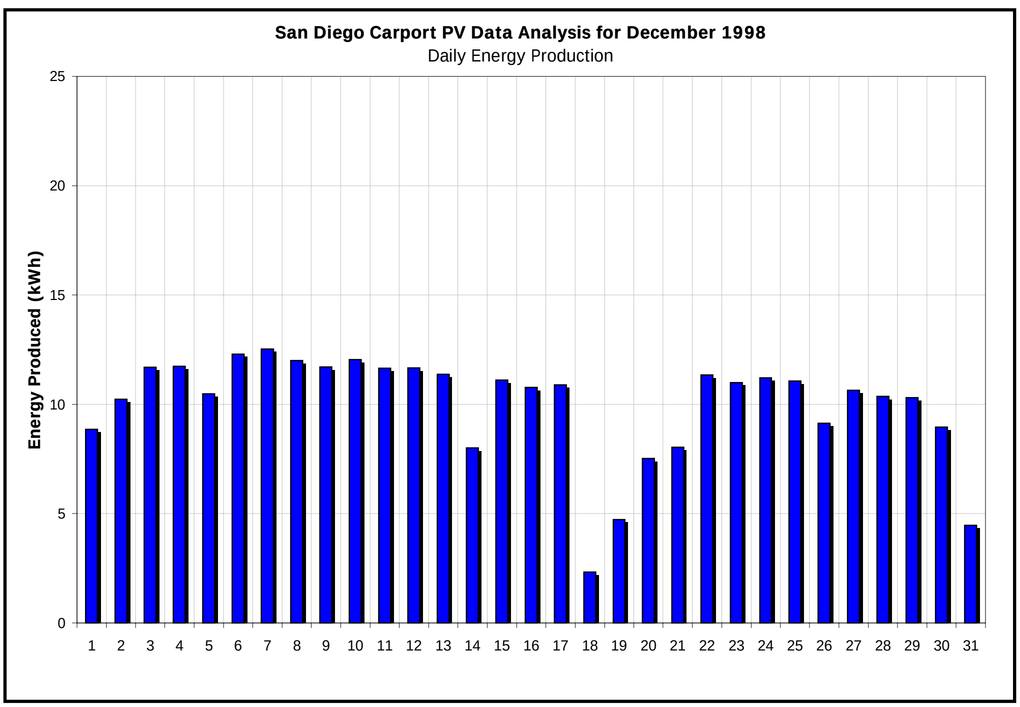

Figure A- 9. Daily Energy Production - December 1998

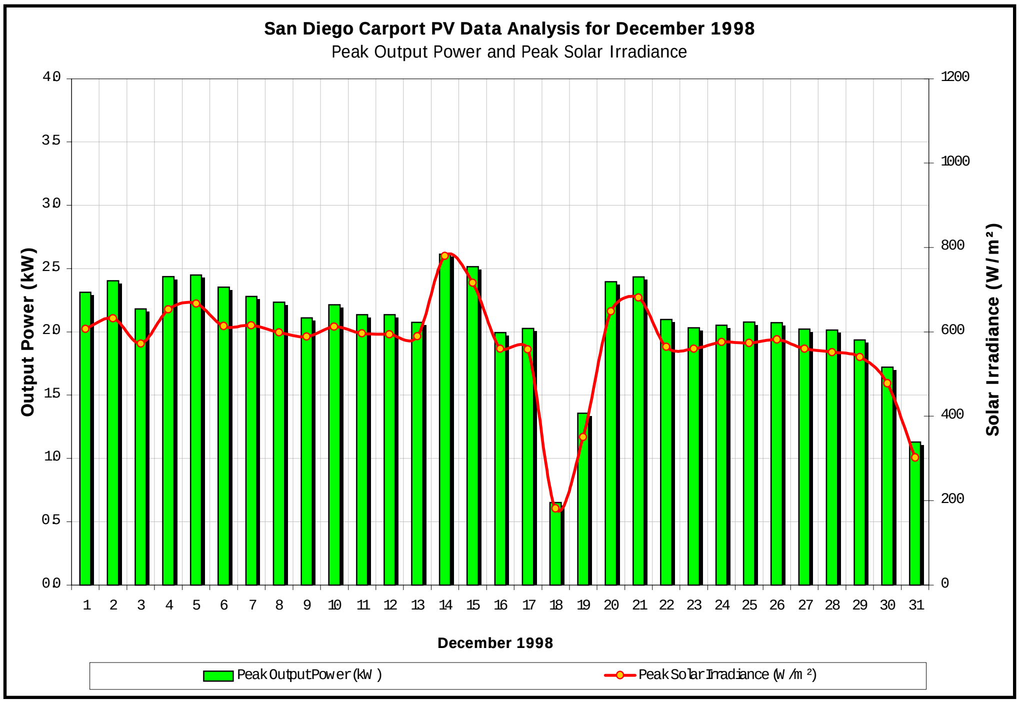

Figure A- 10. Peak Power and Peak Solar Irradiance - December 1998

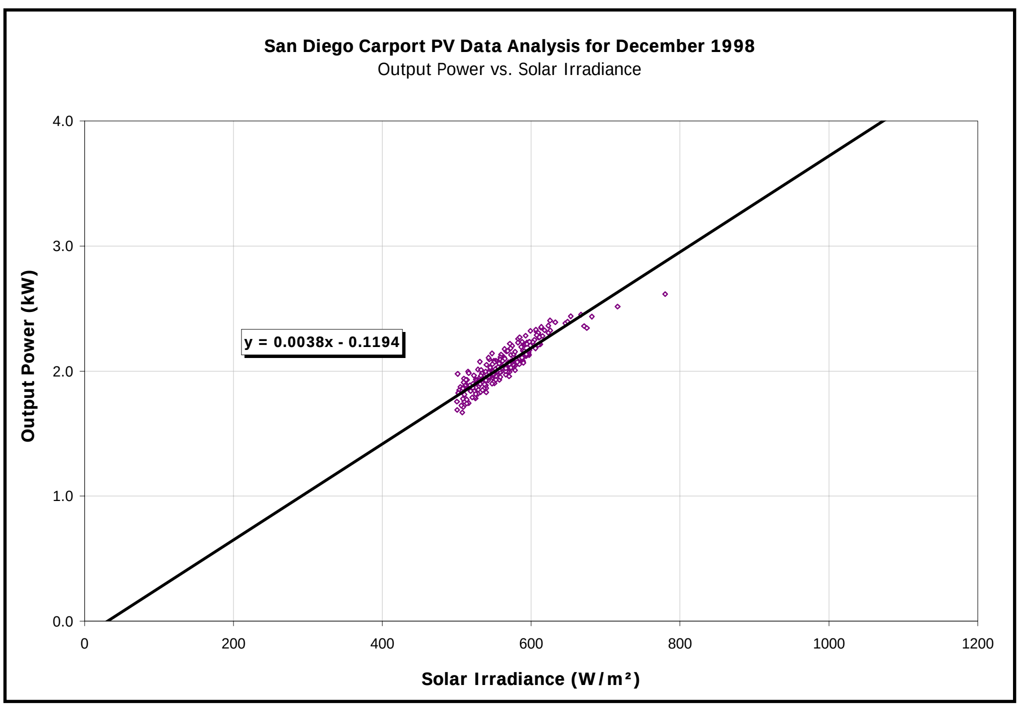

Figure A- 11. Output Power vs. Solar Irradiance - December 1998

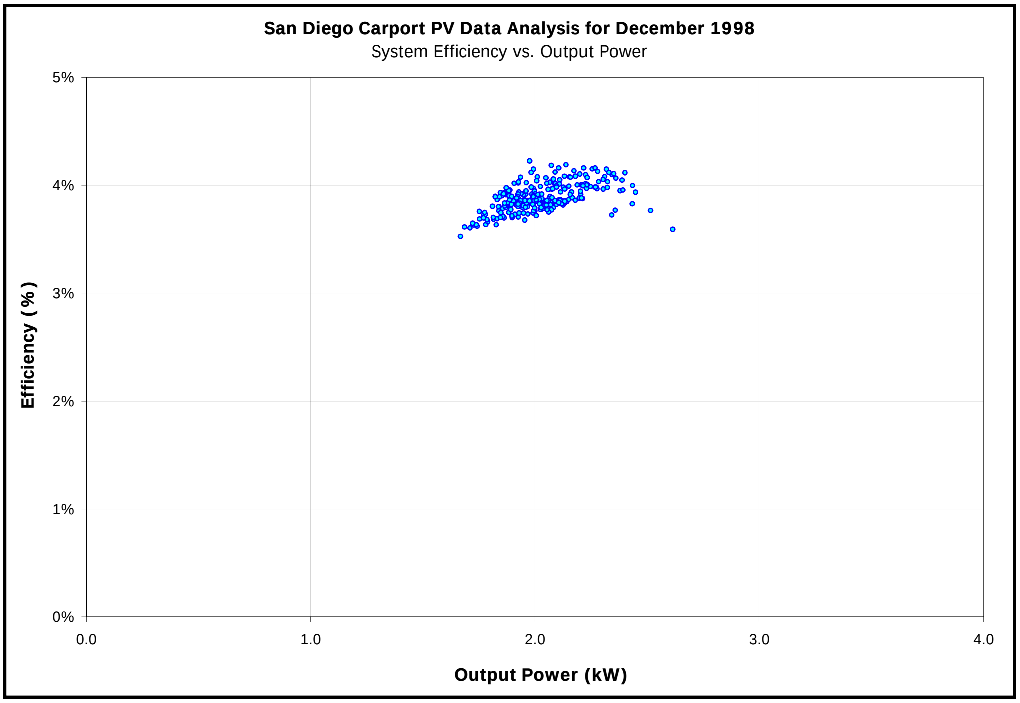

Figure A- 12. Efficiency vs. Output Power - December 1998

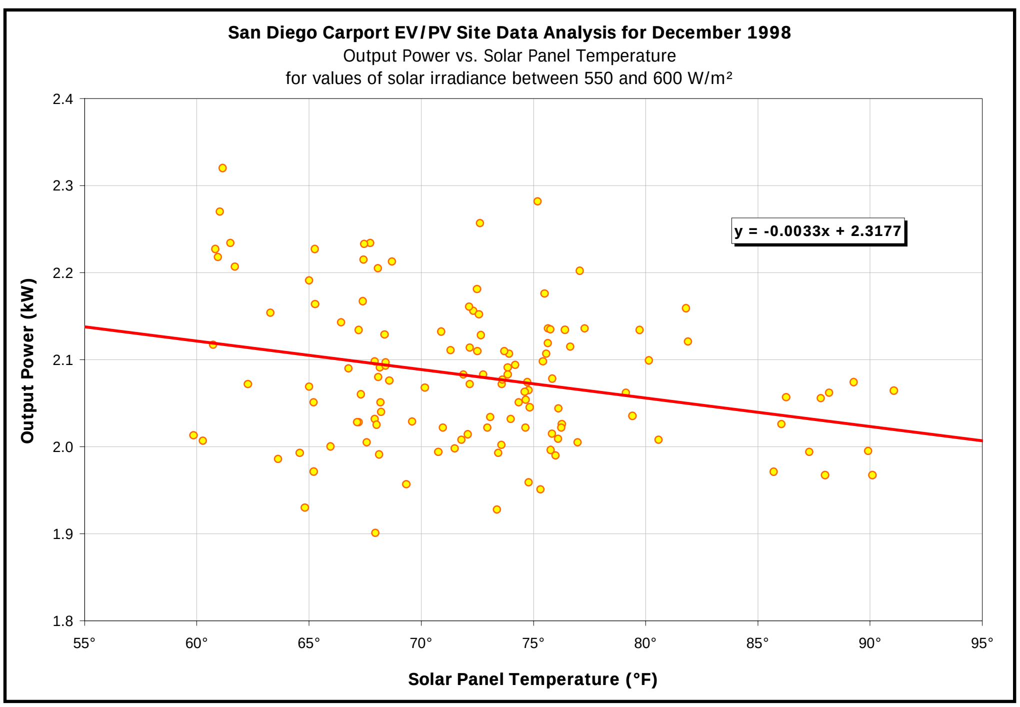

Figure A- 13. Output Power vs. Solar Panel Temperature - December 1998

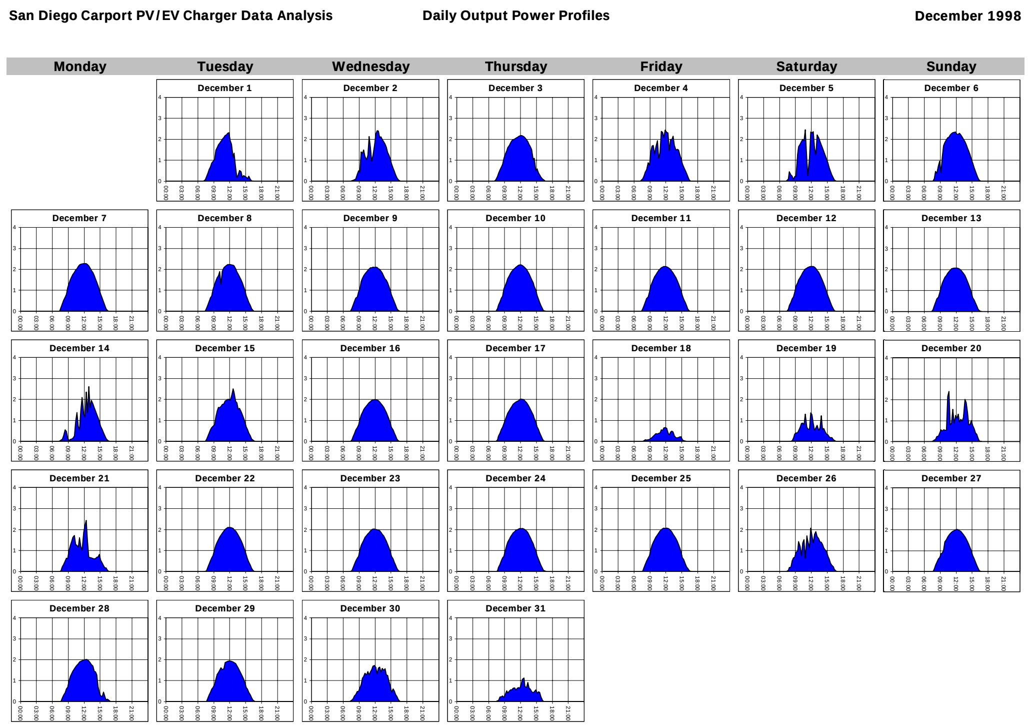

Figure A- 14. PV System Power Output Daily Thumbnails - December 1998

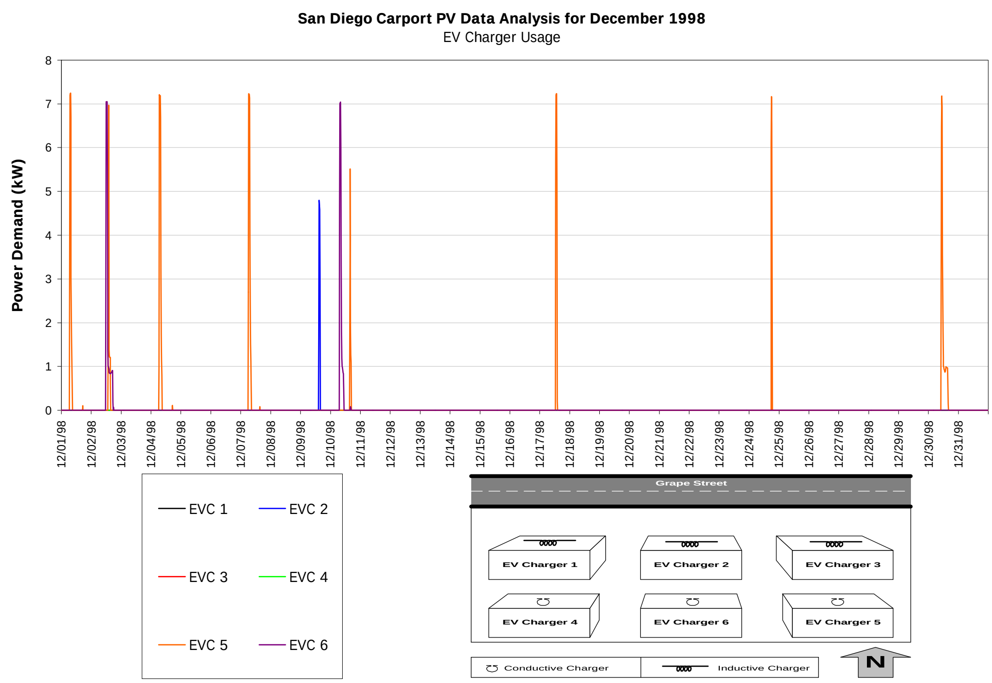

Figure A- 15. EV Charger Demand Profile - December 1998

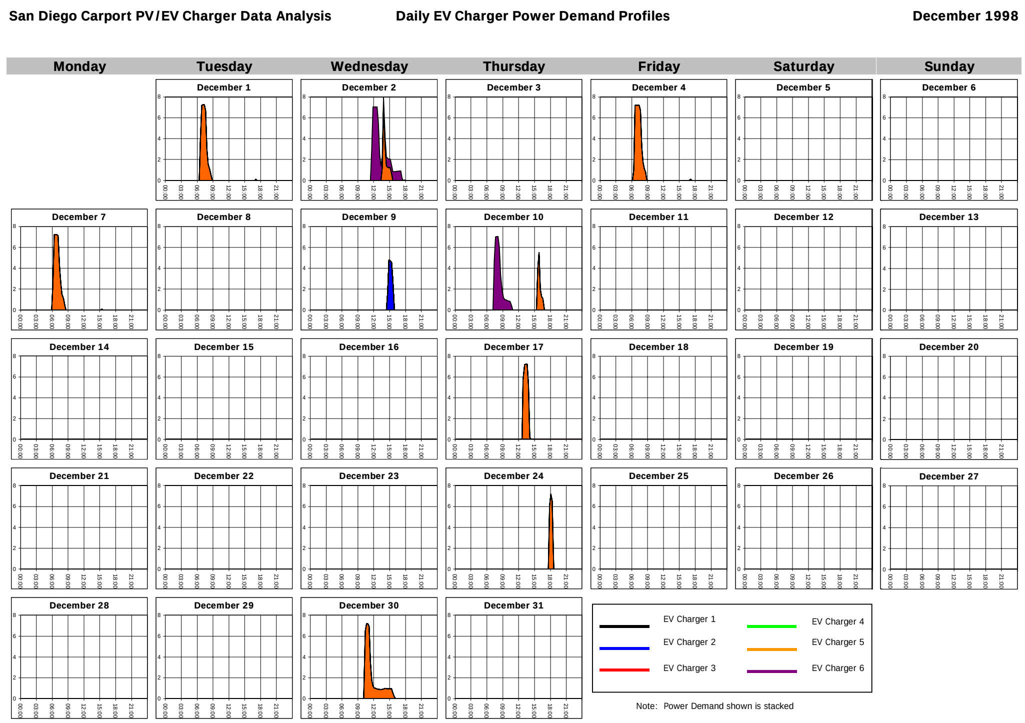

Figure A- 16. EV Charger Usage Daily Thumbnails - December 1998

January 1999

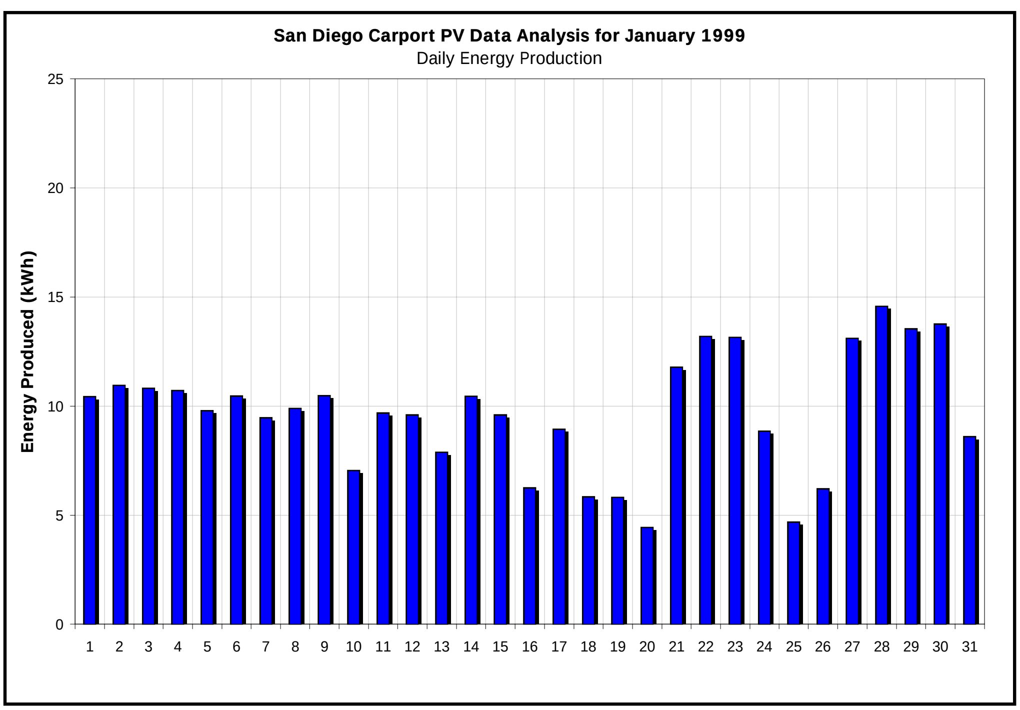

Figure A- 17. Daily Energy Production - January 1999

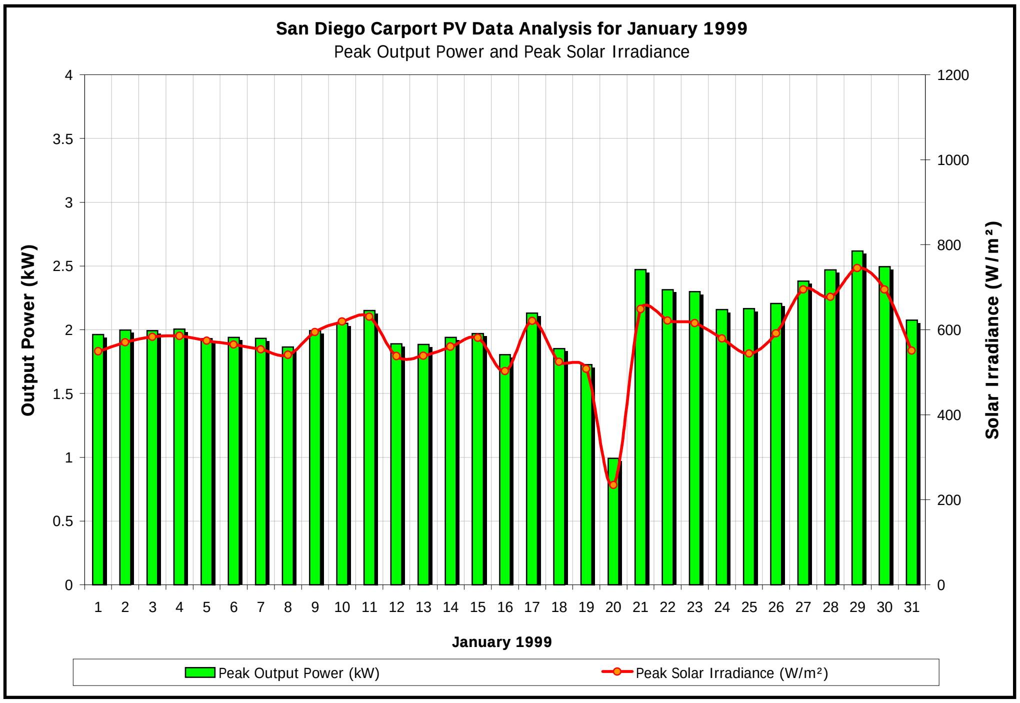

Figure A- 18. Peak Output Power and Peak Solar Irradiance - January 1999

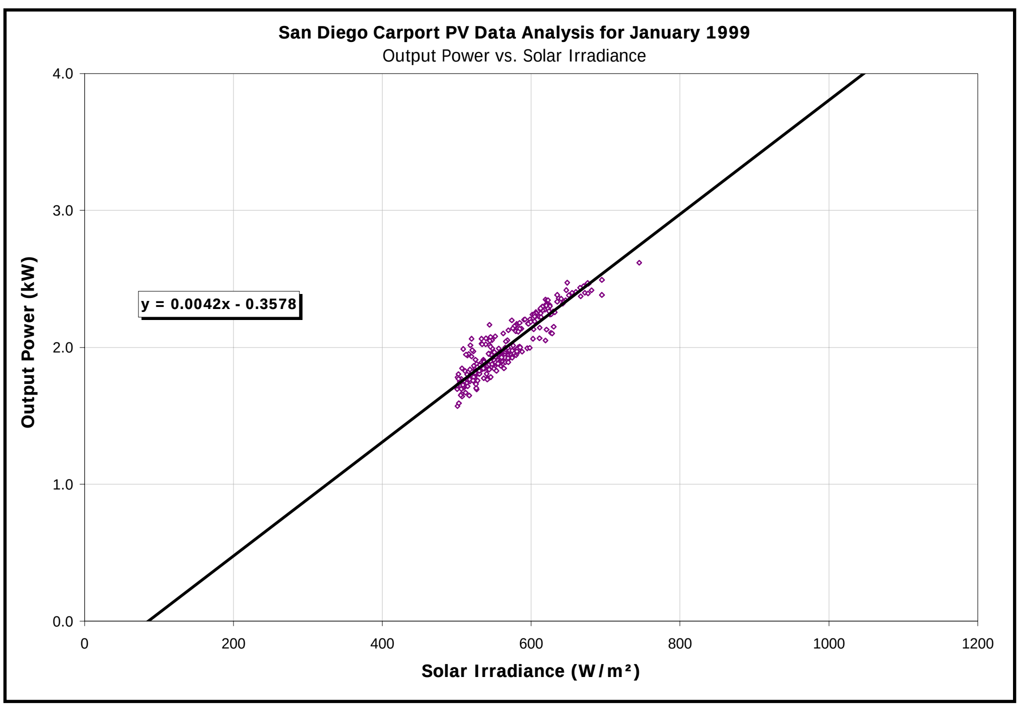

Figure A- 19. Output Power vs. Solar Irradiance - January 1999

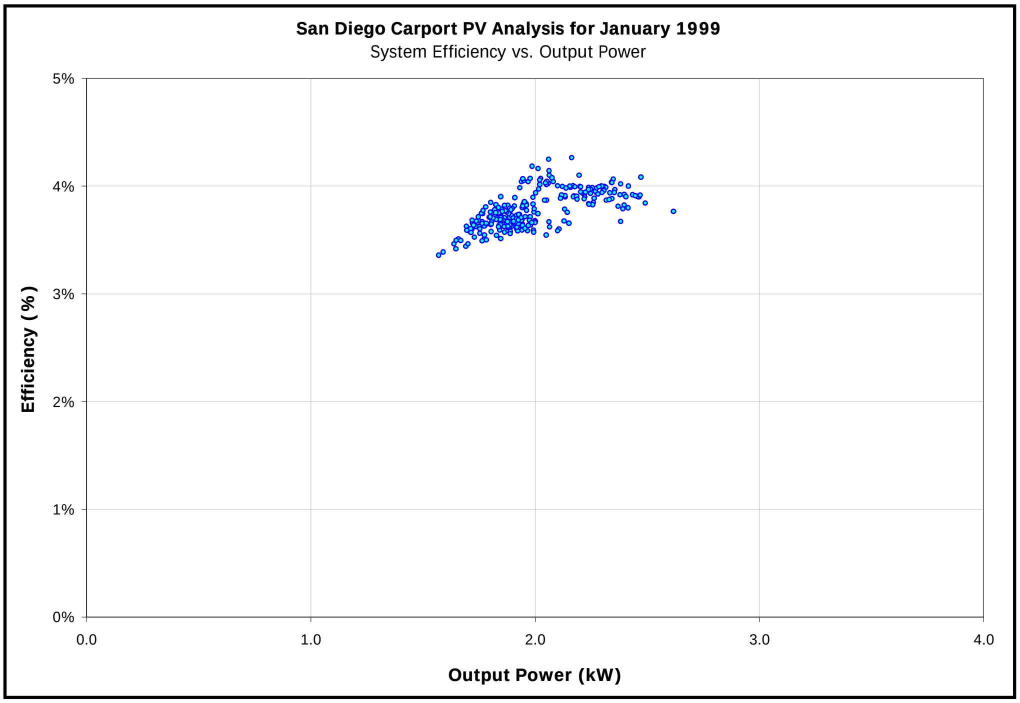

Figure A- 20. Efficiency vs. Output Power - January 1999

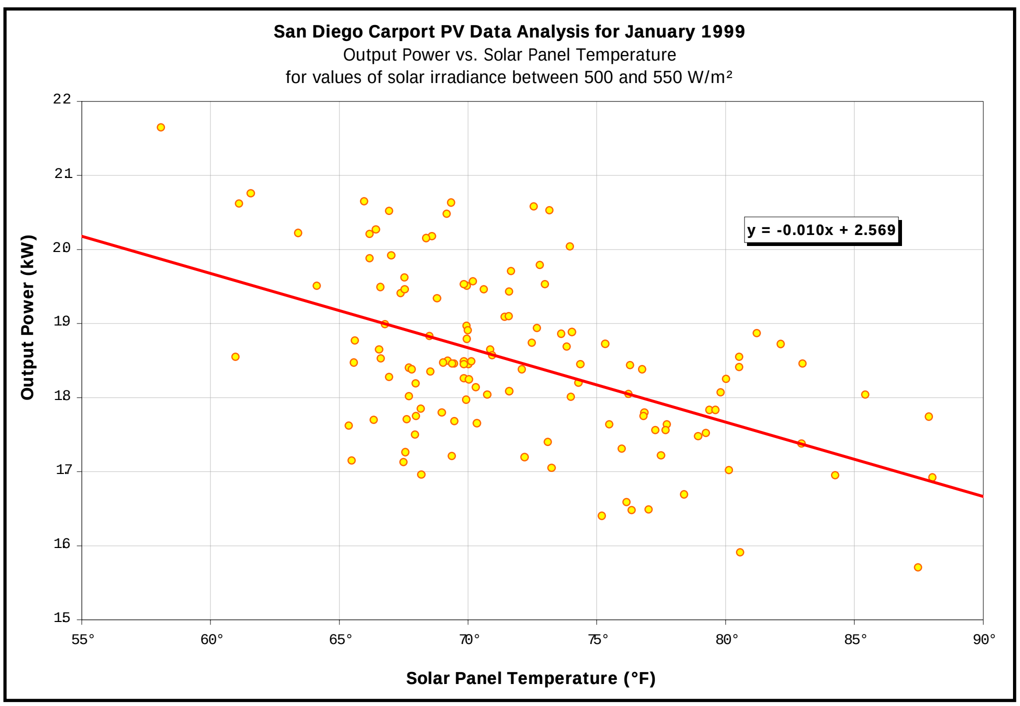

Figure A- 21. Output Power vs. Solar Panel Temperature - January 1999

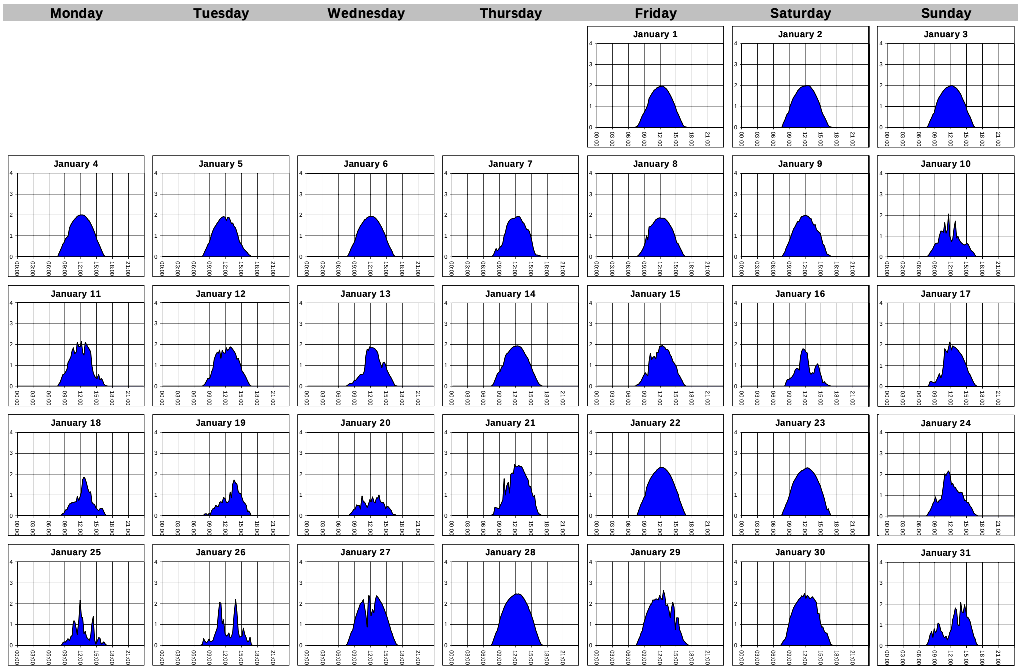

Figure A- 22. PV System Power Output Daily Thumbnails - January 1999

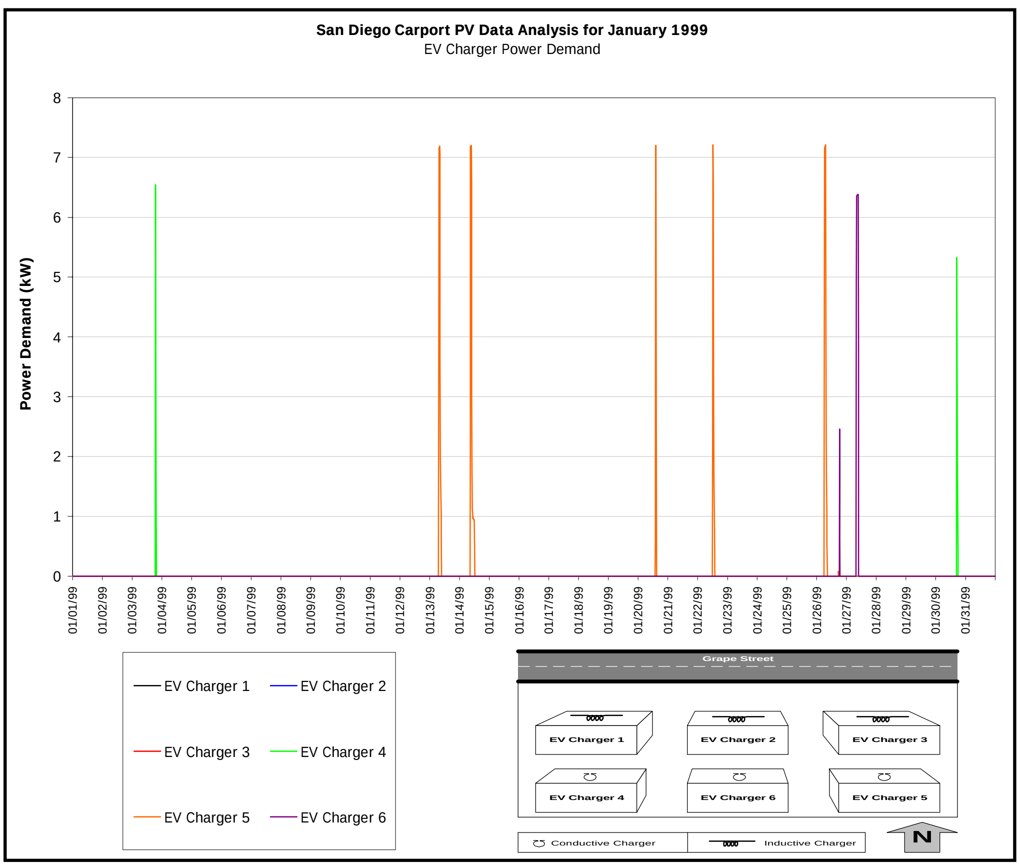

Figure A- 23. EV Charger Demand Profile - January 1999

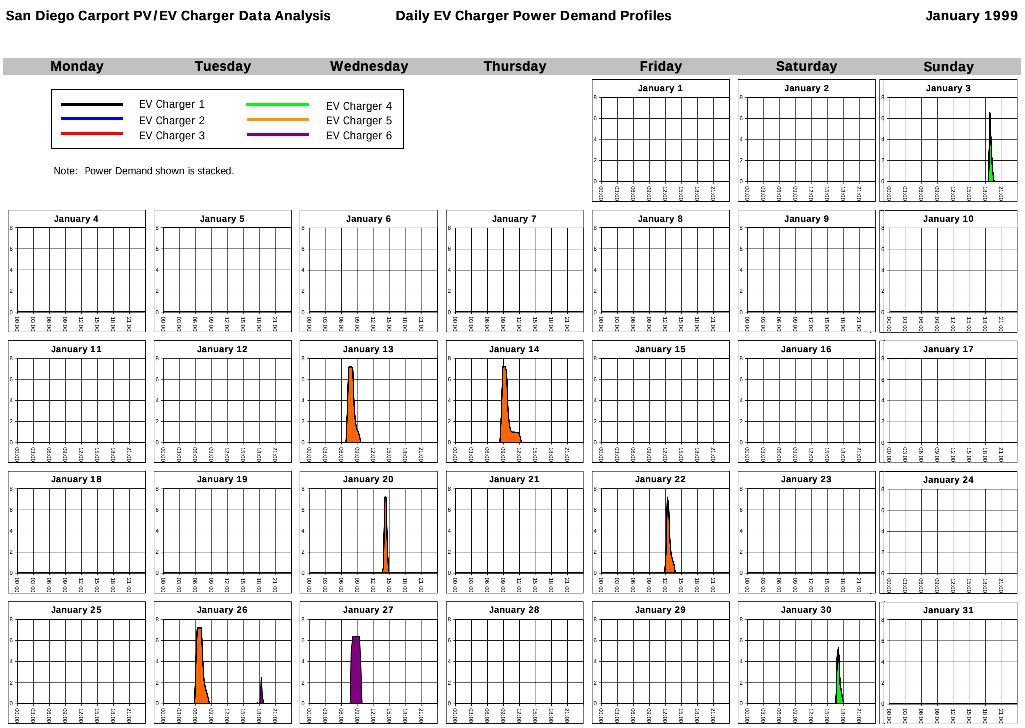

Figure A- 24. EV Charger Usage Daily Thumbnails - January 1999

February 1999

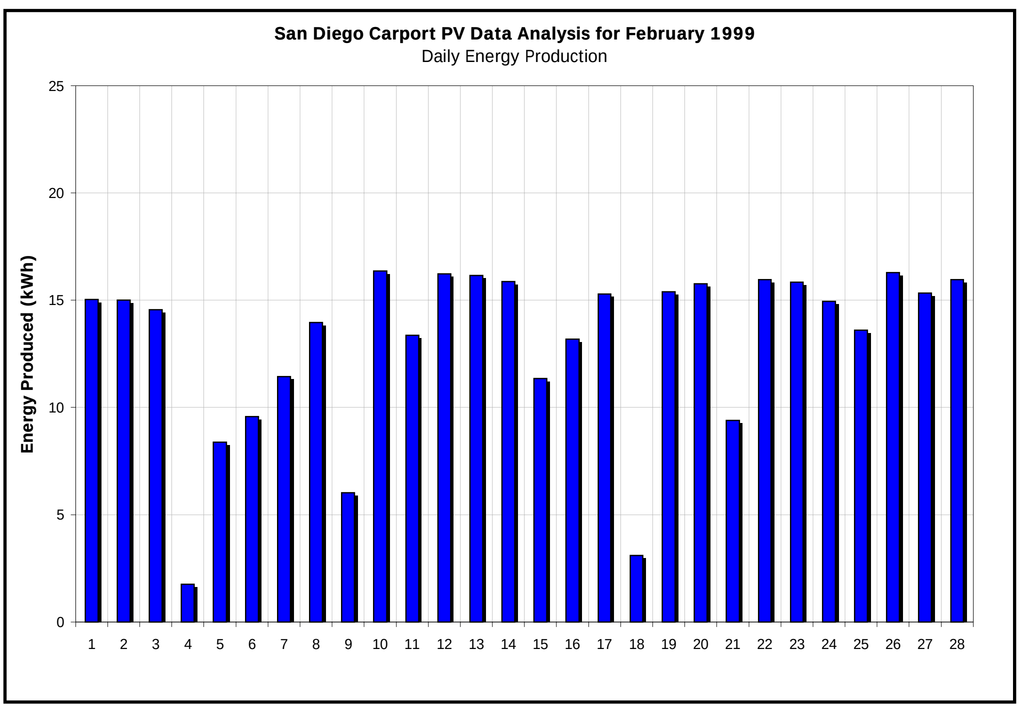

Figure A- 25. Daily Energy Production - February 1999

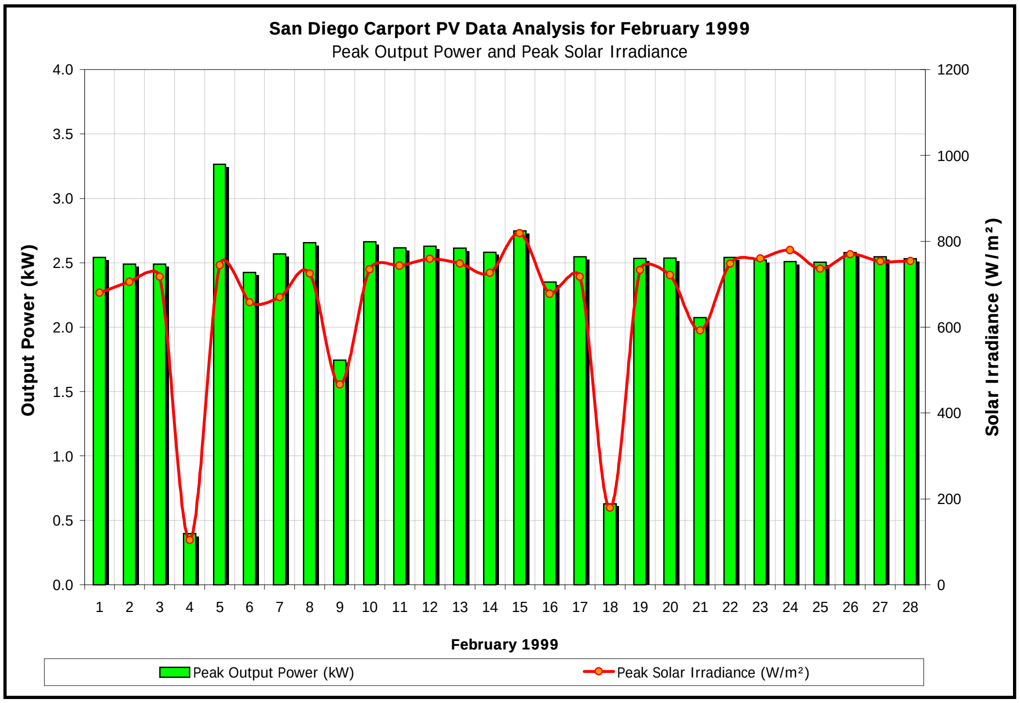

Figure A- 26. Peak Power and Peak Solar Irradiance - February 1999

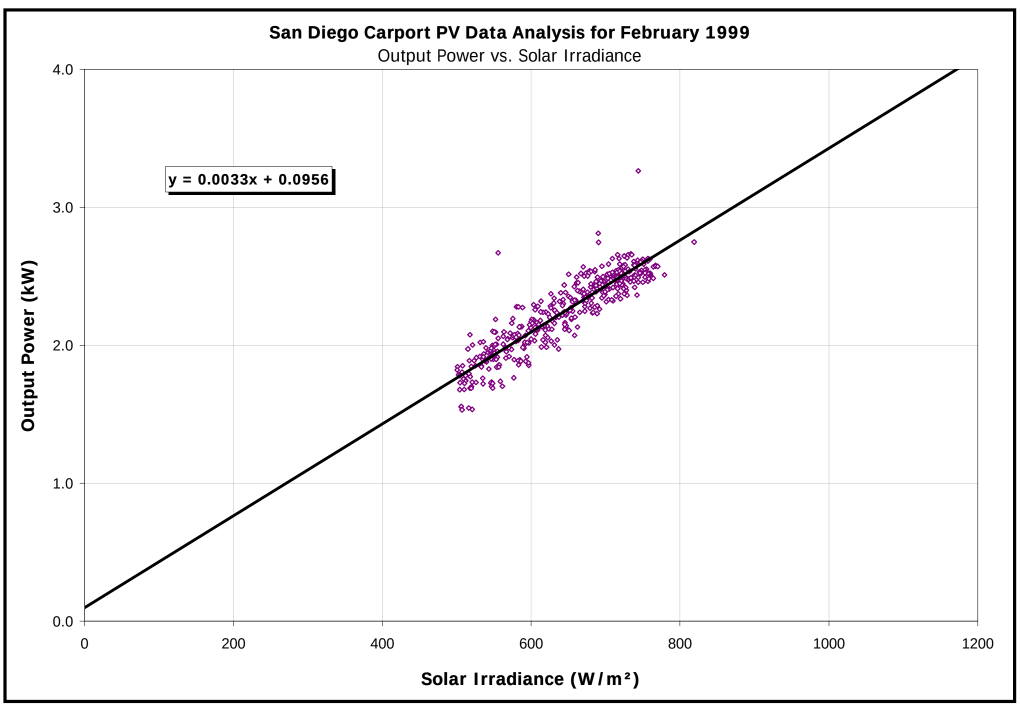

Figure A- 27. Output Power vs. Solar Irradiance - February 1999

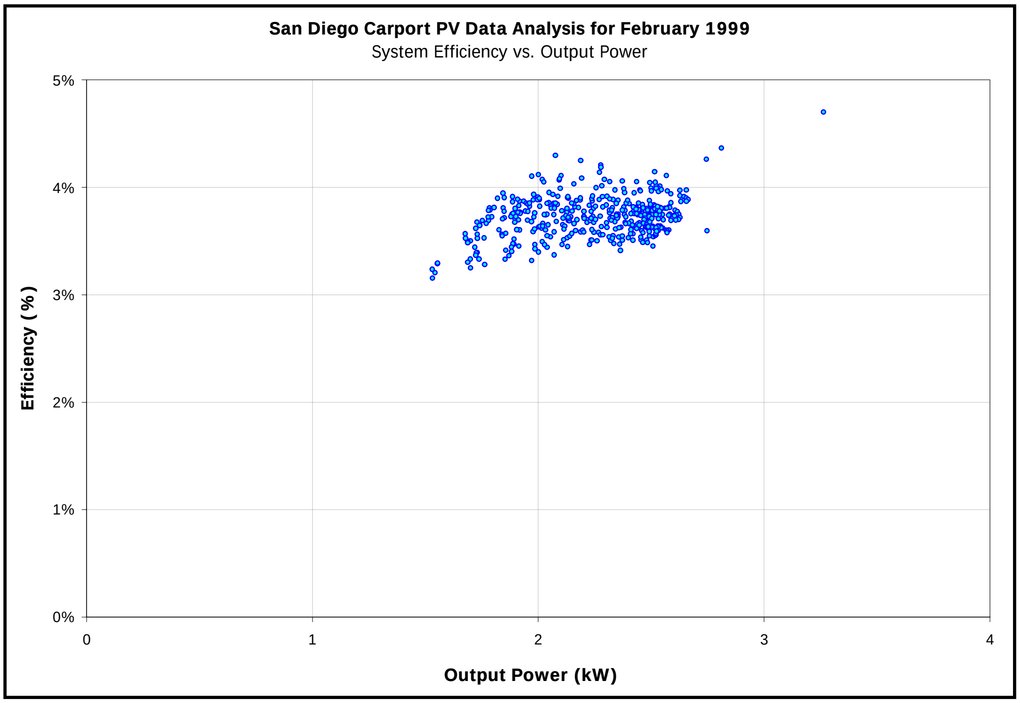

Figure A- 28. Efficiency vs. Output Power - February 1999

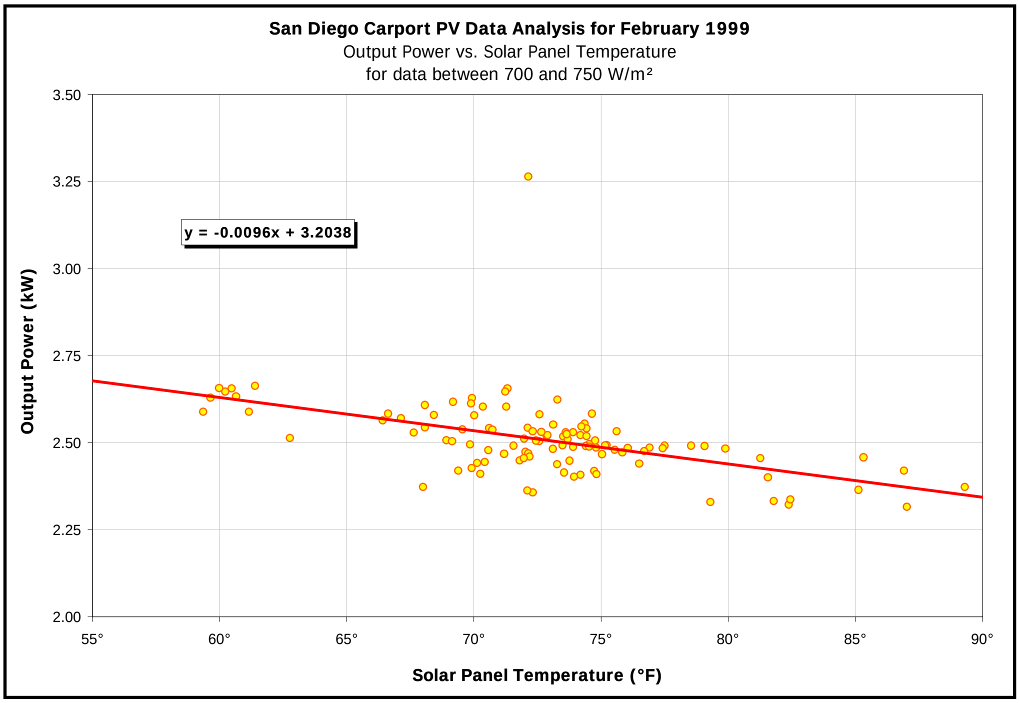

Figure A- 29. Output Power vs. Solar Panel Temperature - February 1999

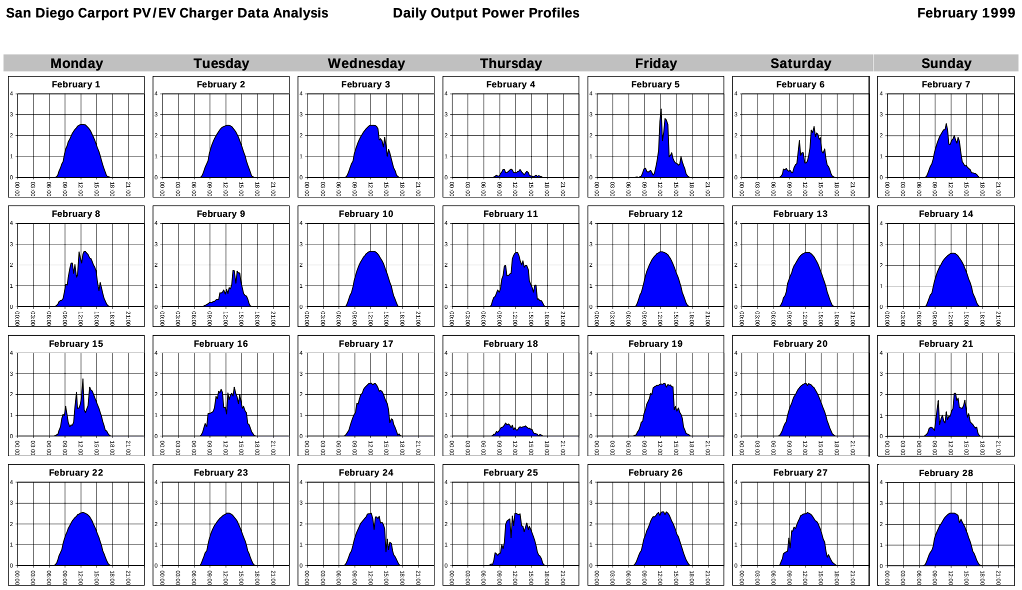

Figure A- 30. PV System Power Output Daily Thumbnails - February 1999

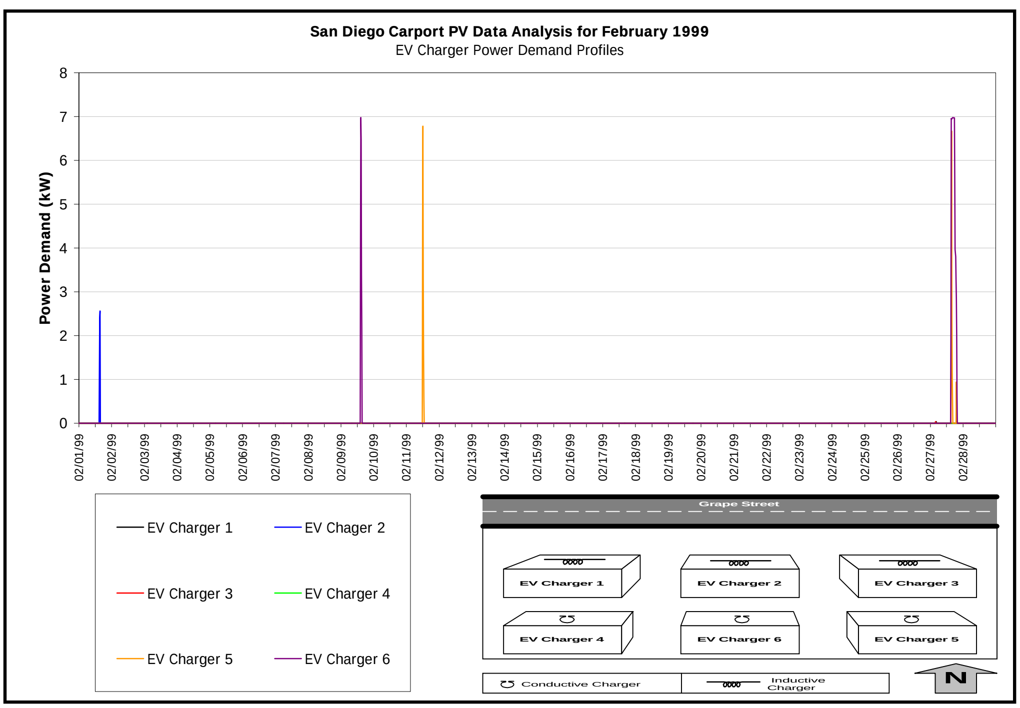

Figure A- 31. EV Charger Demand Profile - February 1999

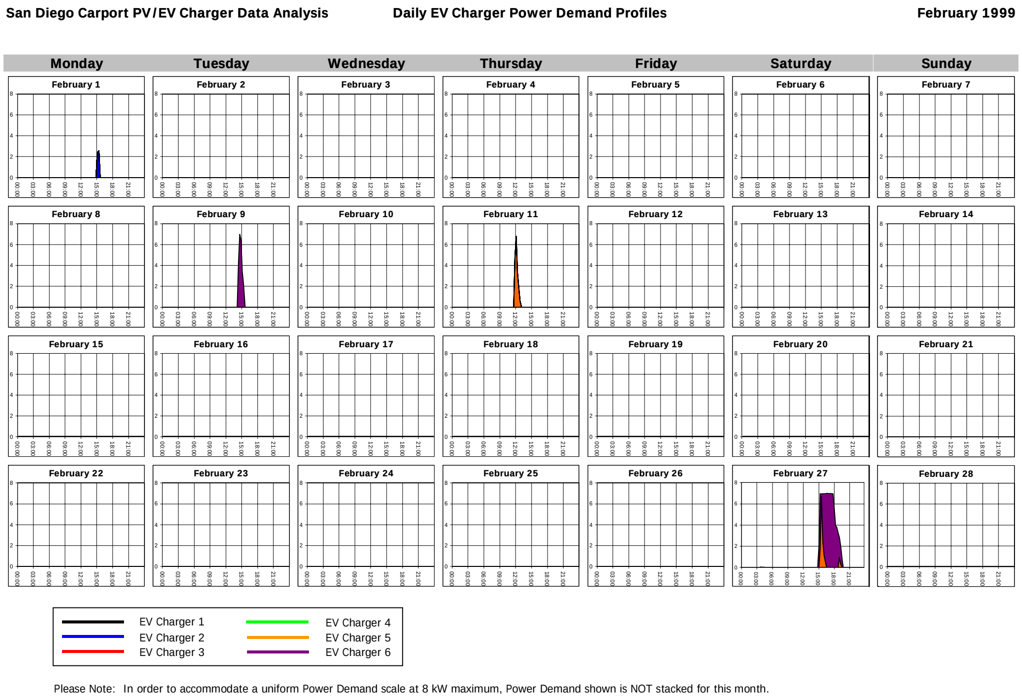

Figure A- 32. EV Charger Usage Daily Thumbnails - February 1999

March 1999

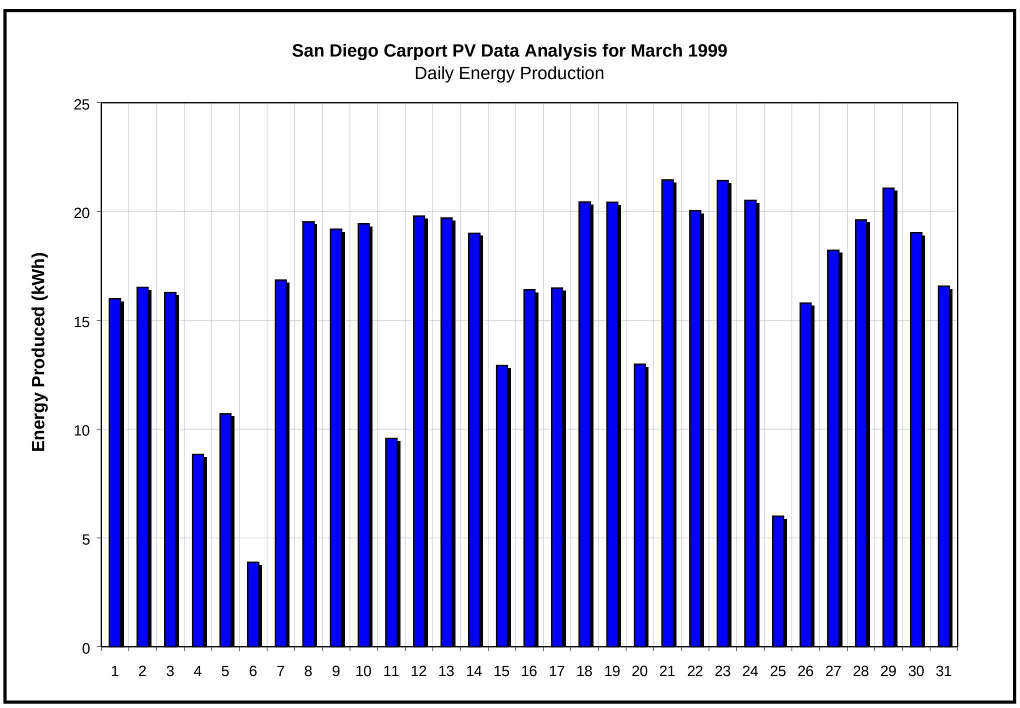

Figure A- 33. Daily Energy Production - March 1999

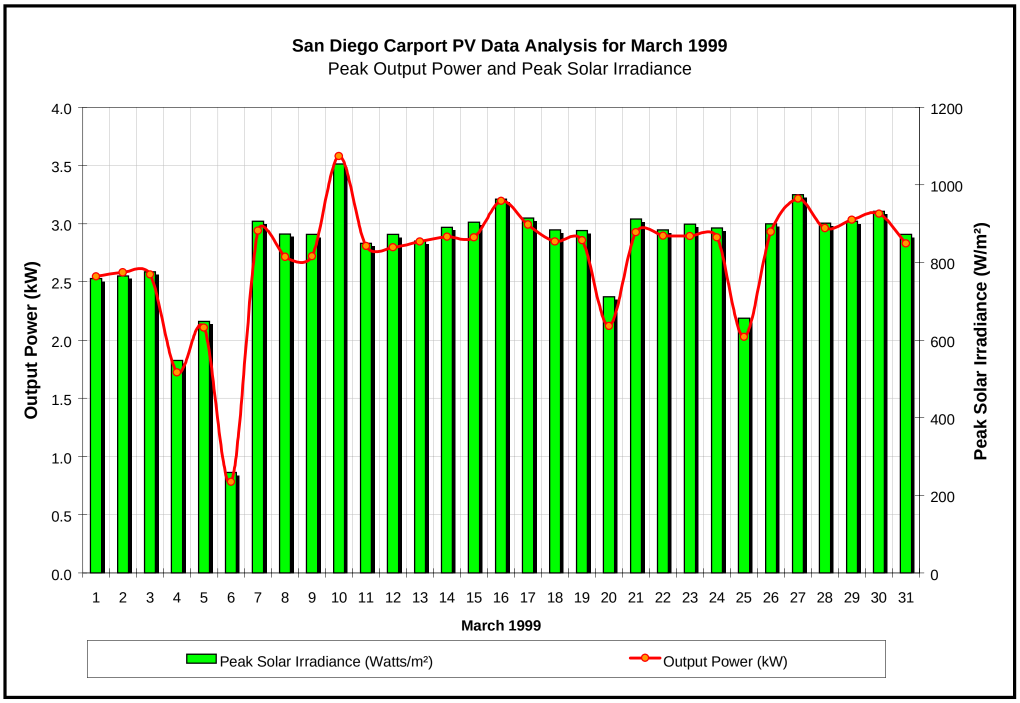

Figure A- 34. Peak Power and Peak Solar Irradiance - March 1999

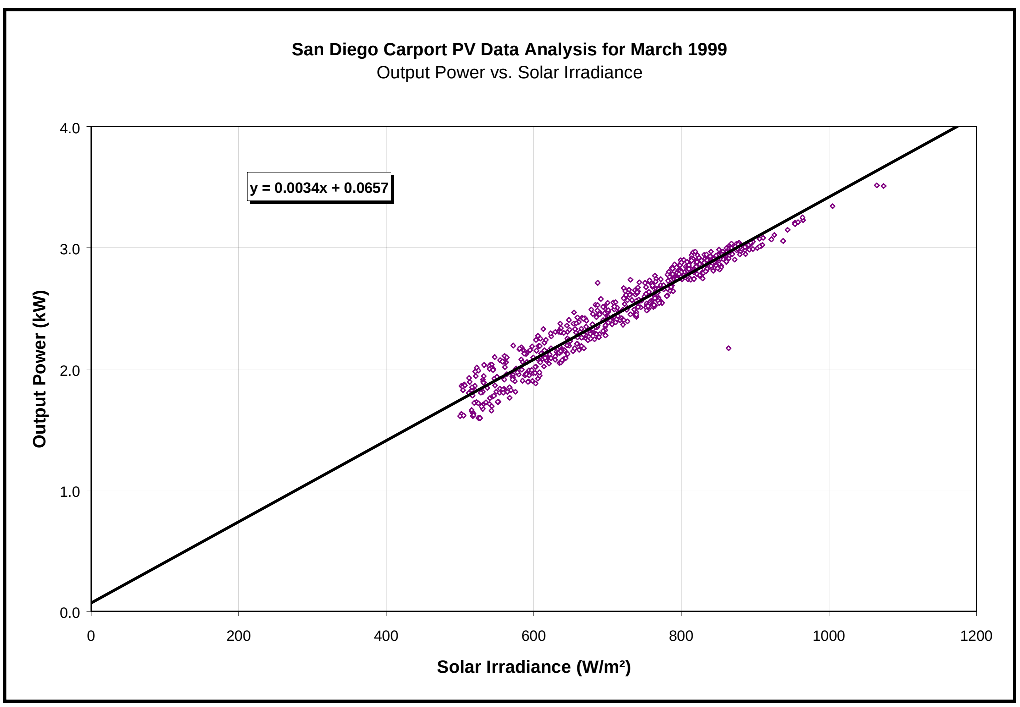

Figure A- 35. Output Power vs. Solar Irradiance - March 1999

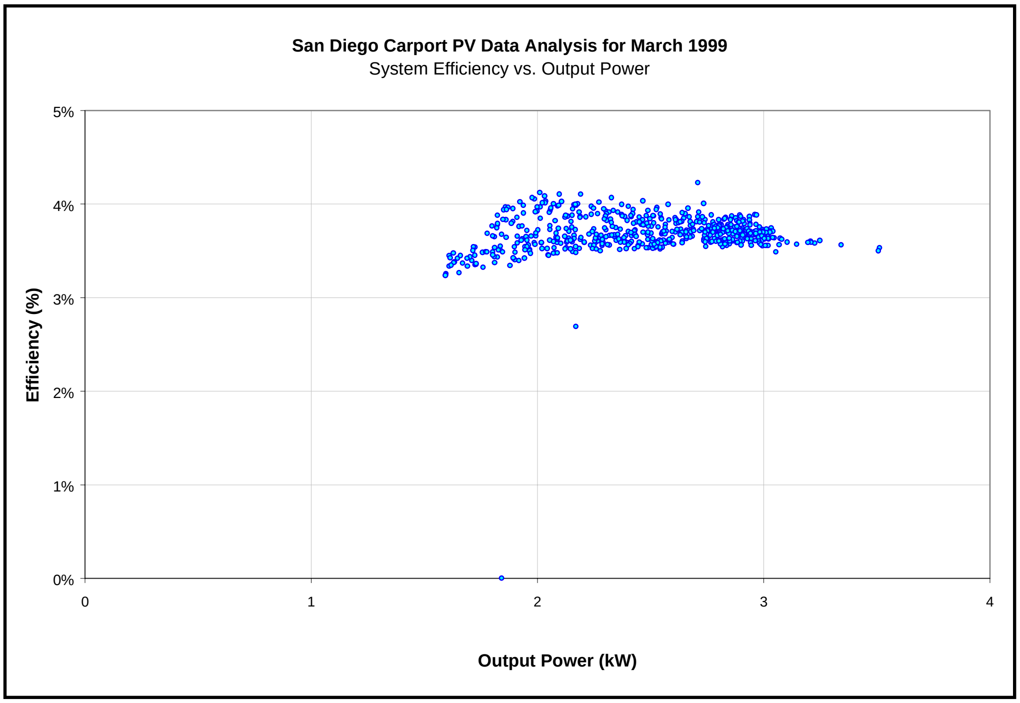

Figure A- 36. Efficiency vs. Output Power - March 1999

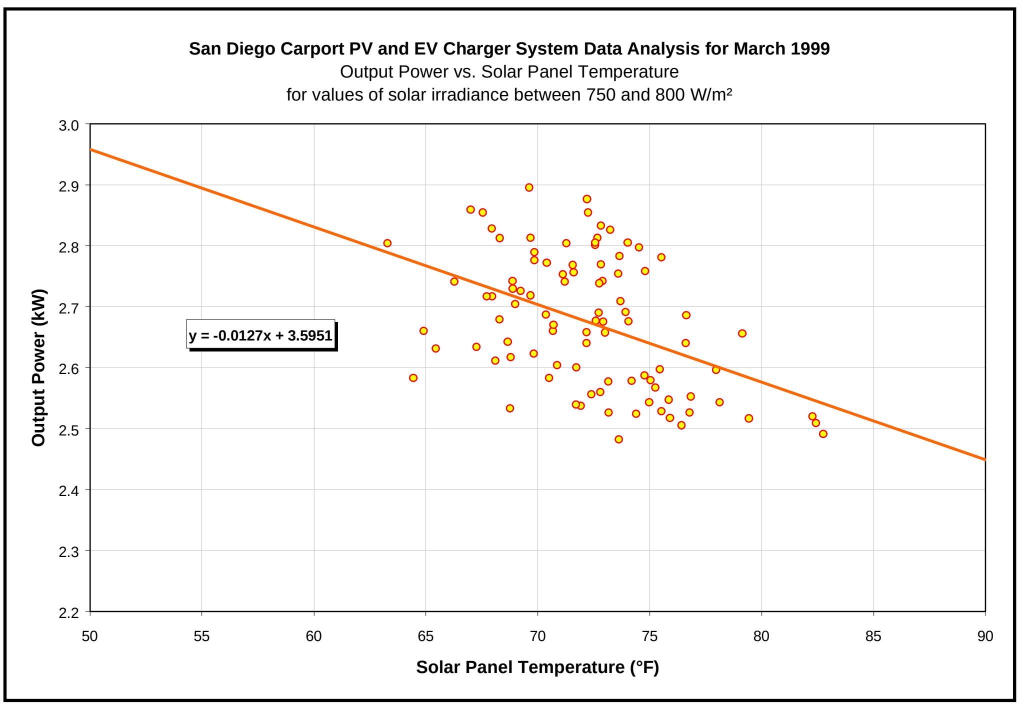

Figure A- 37. Output Power vs. Solar Panel Temperature - March 1999

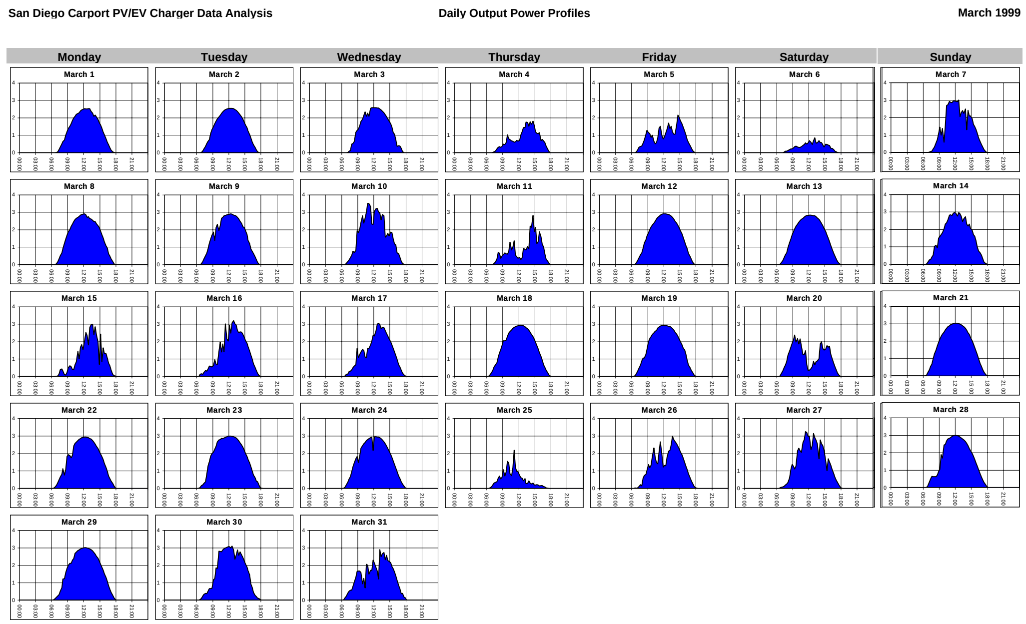

Figure A- 38. EV Charger Demand Profile - March 1999

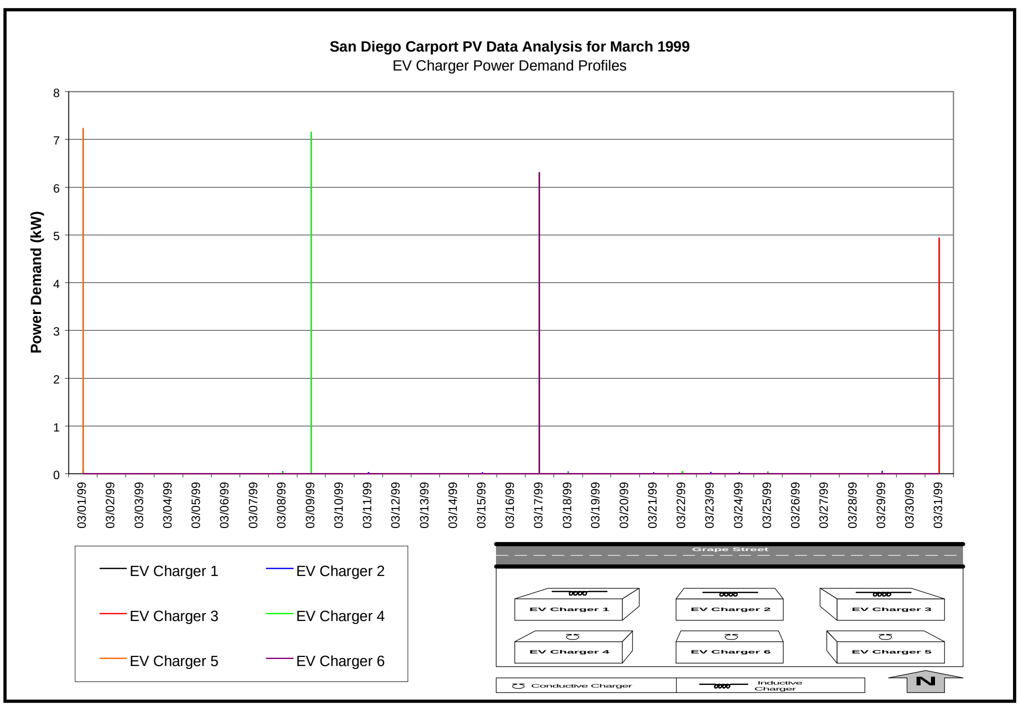

Figure A- 39. EV Charger Demand Profile - March 1999

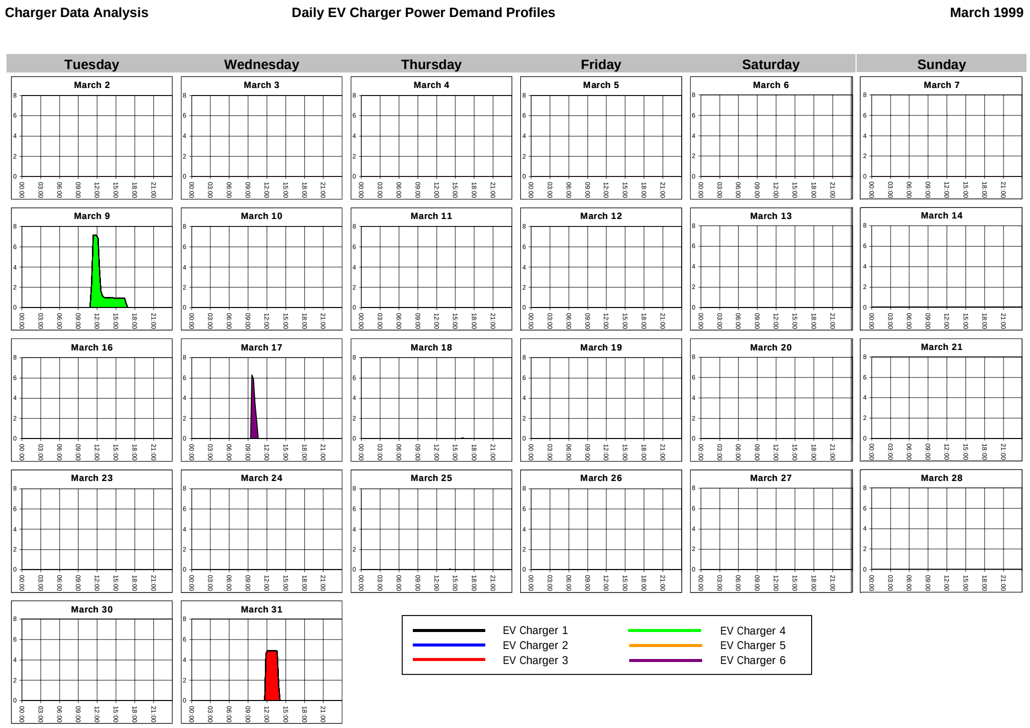

Figure A- 40. EV Charger Usage Daily Thumbnails - March 1999

April 1999

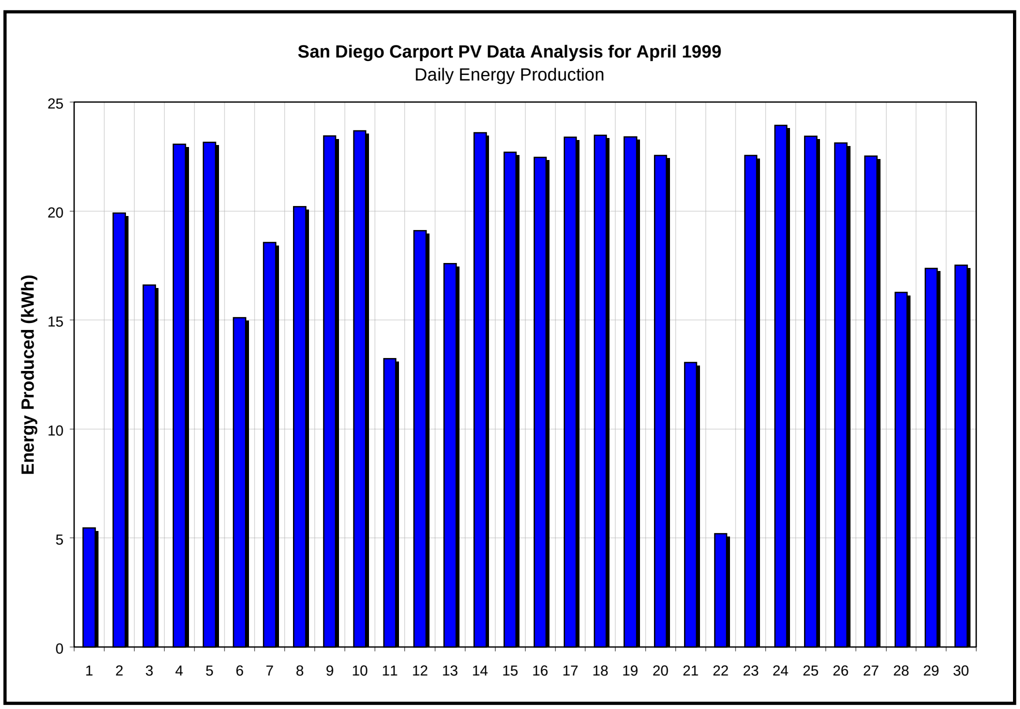

Figure A- 41. Daily Energy Production - April 1999

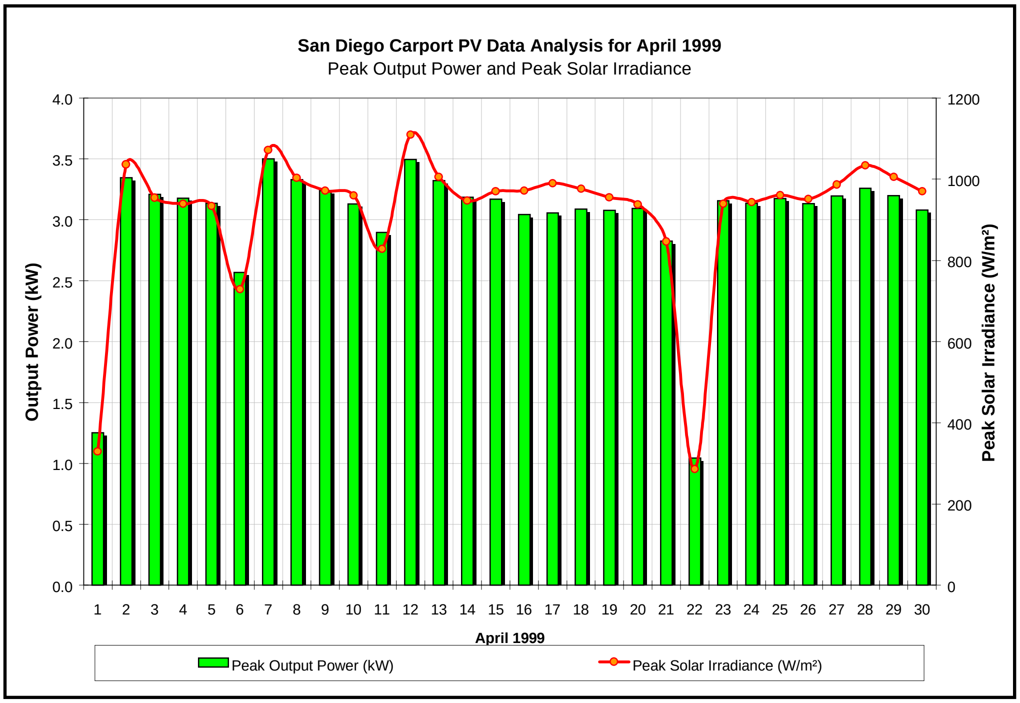

Figure A- 42. Peak Power and Peak Solar Irradiance - April 1999

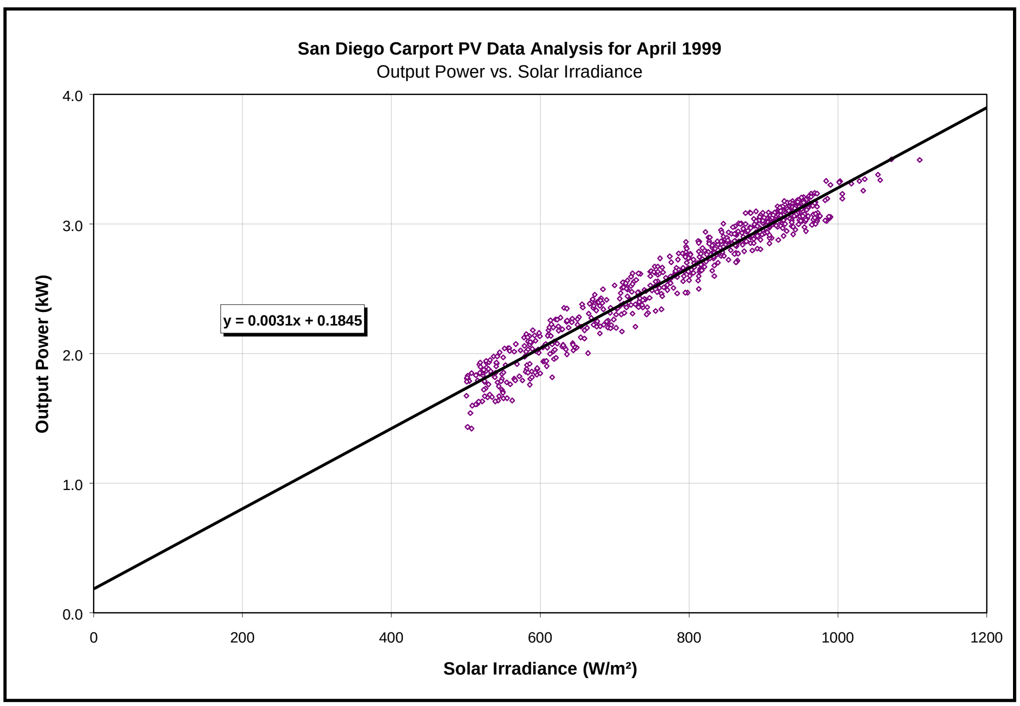

Figure A- 43. Output Power vs. Solar Irradiance - April 1999

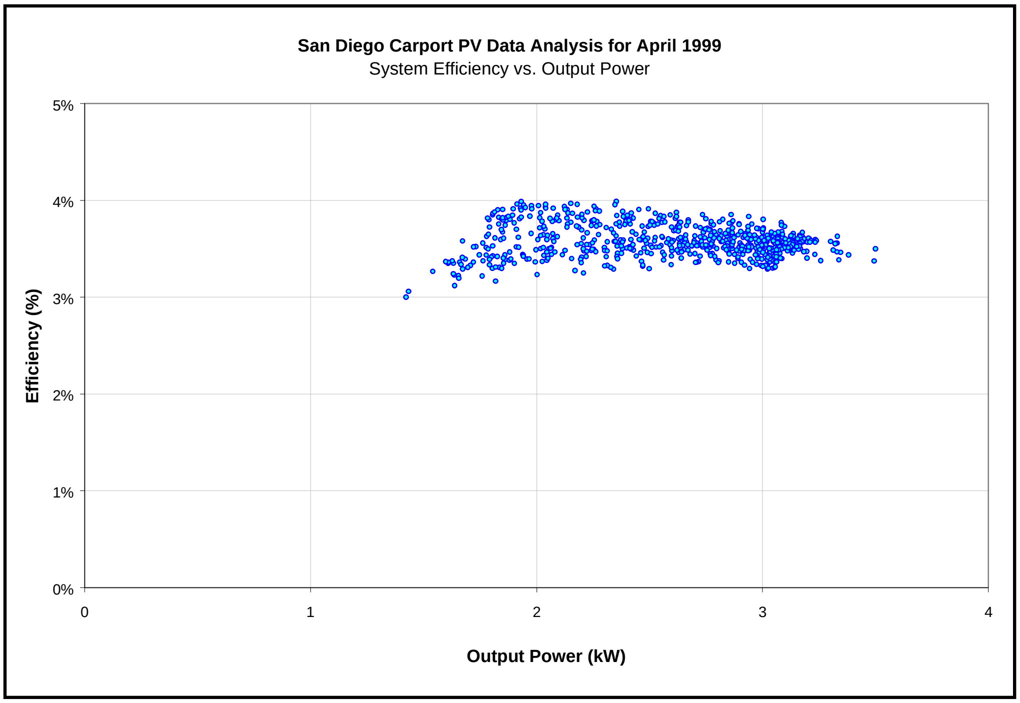

Figure A- 44. Efficiency vs. Output Power - April 1999

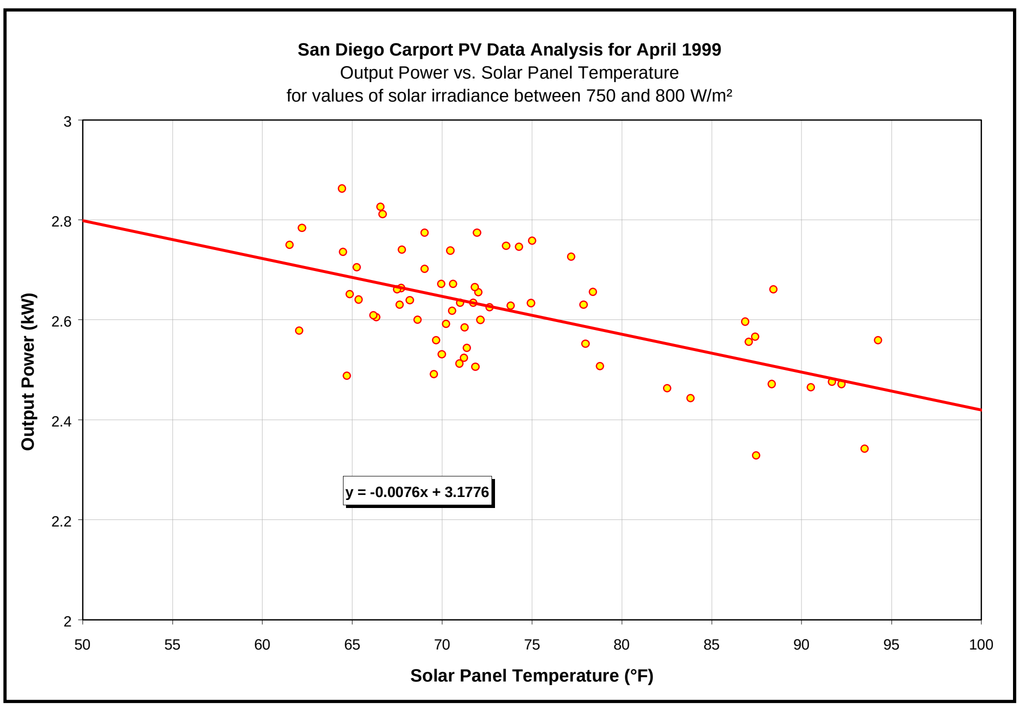

Figure A- 45. Output Power vs. Solar Panel Temperature - April 1999

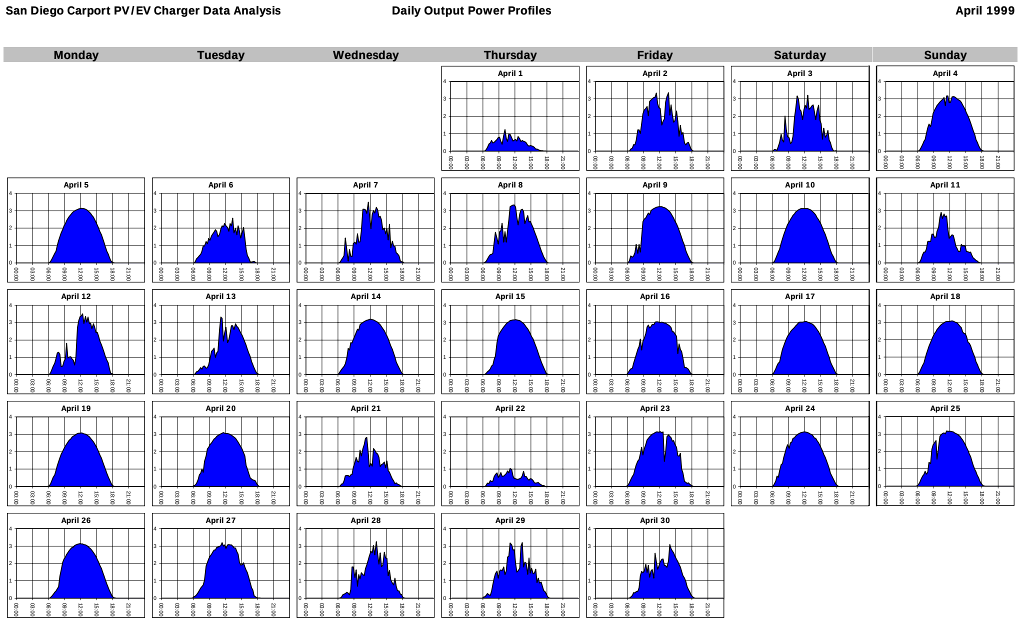

Figure A- 46. PV System Power Output Daily Thumbnails - April 1999

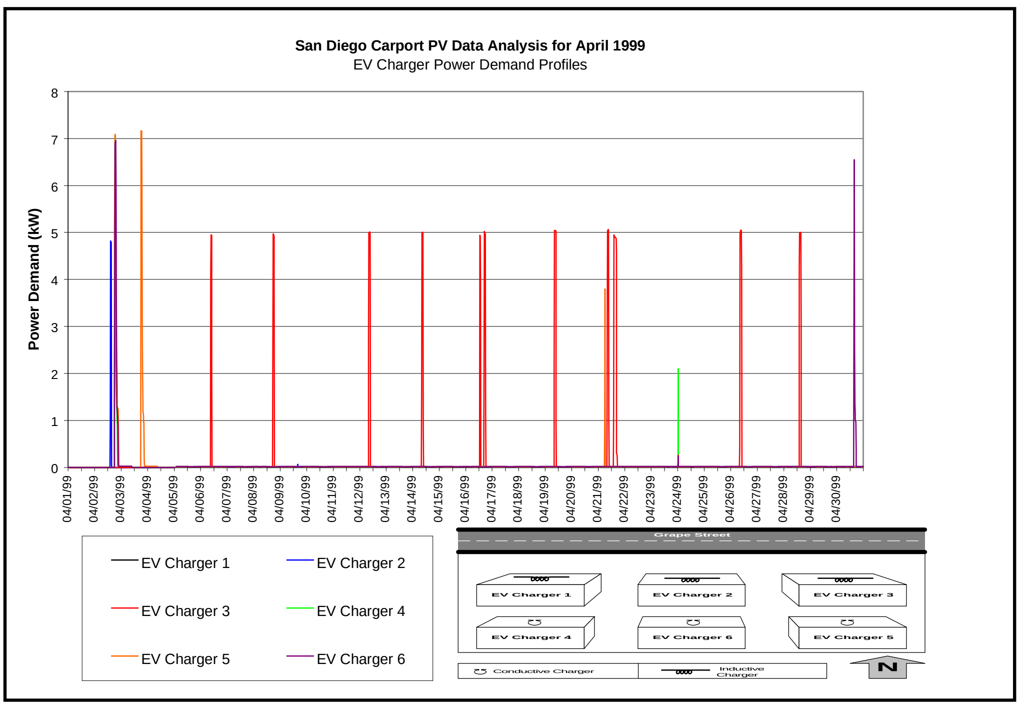

Figure A- 47. EV Charger Demand Profile - April 1999

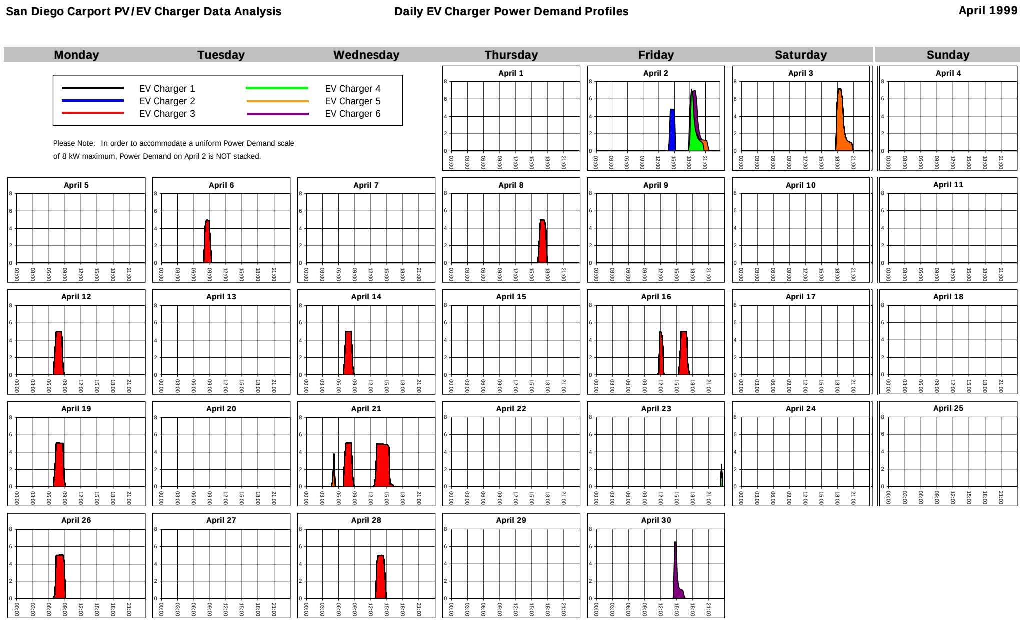

Figure A- 48. EV Charger Usage Daily Thumbnails - April 1999

May 1999

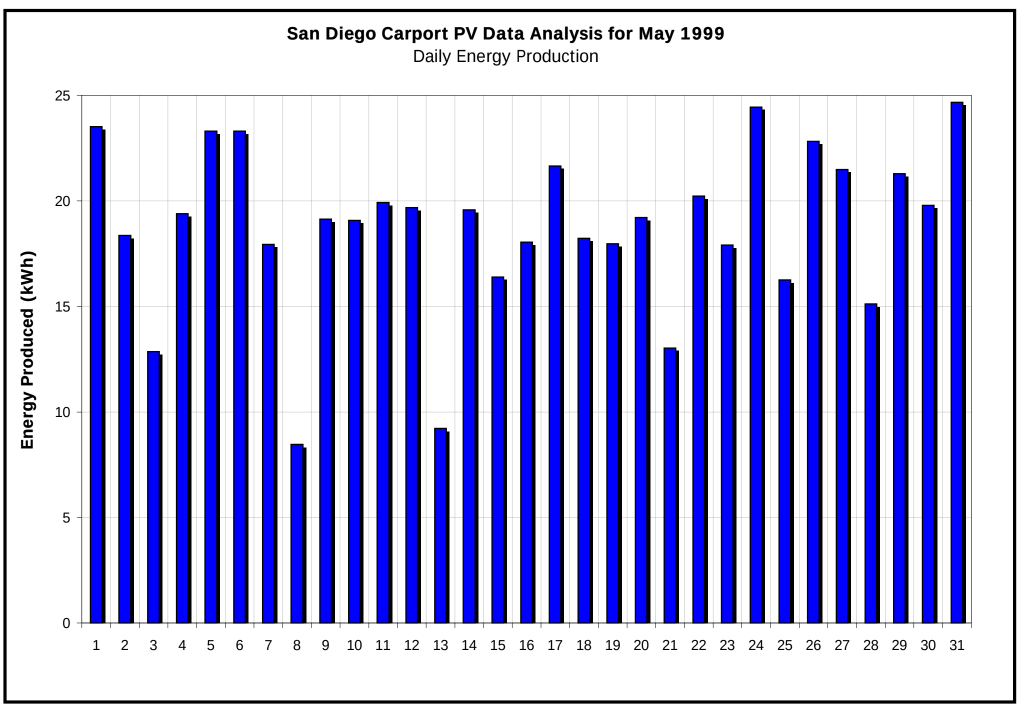

Figure A- 49. Daily Energy Production - May 1999

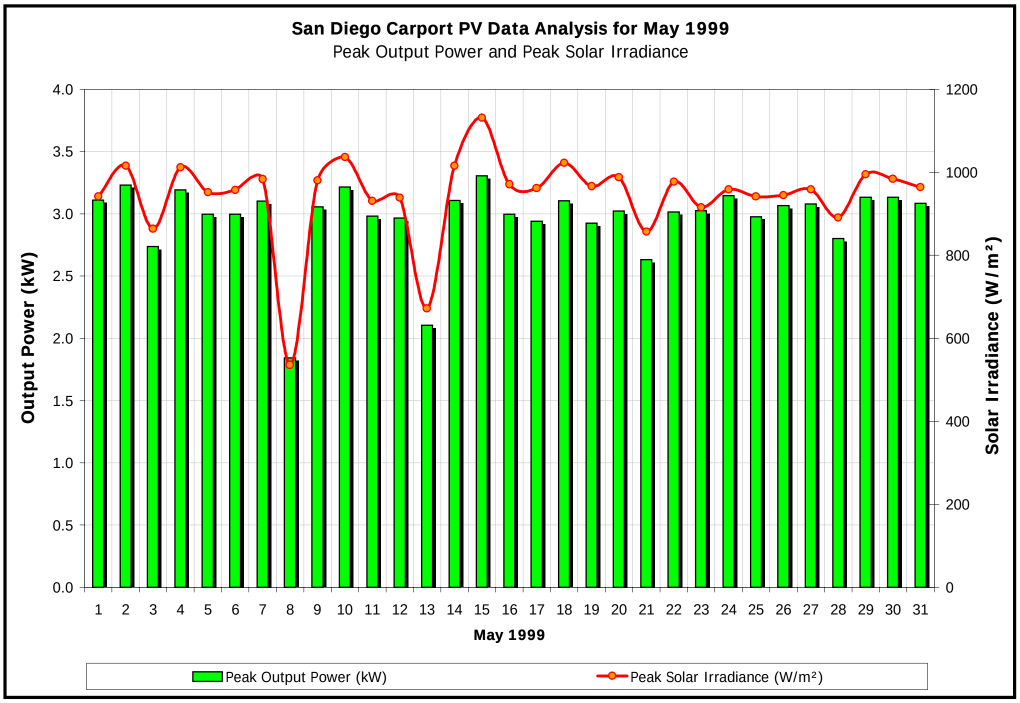

Figure A- 50. Peak Power and Peak Solar Irradiance - May 1999

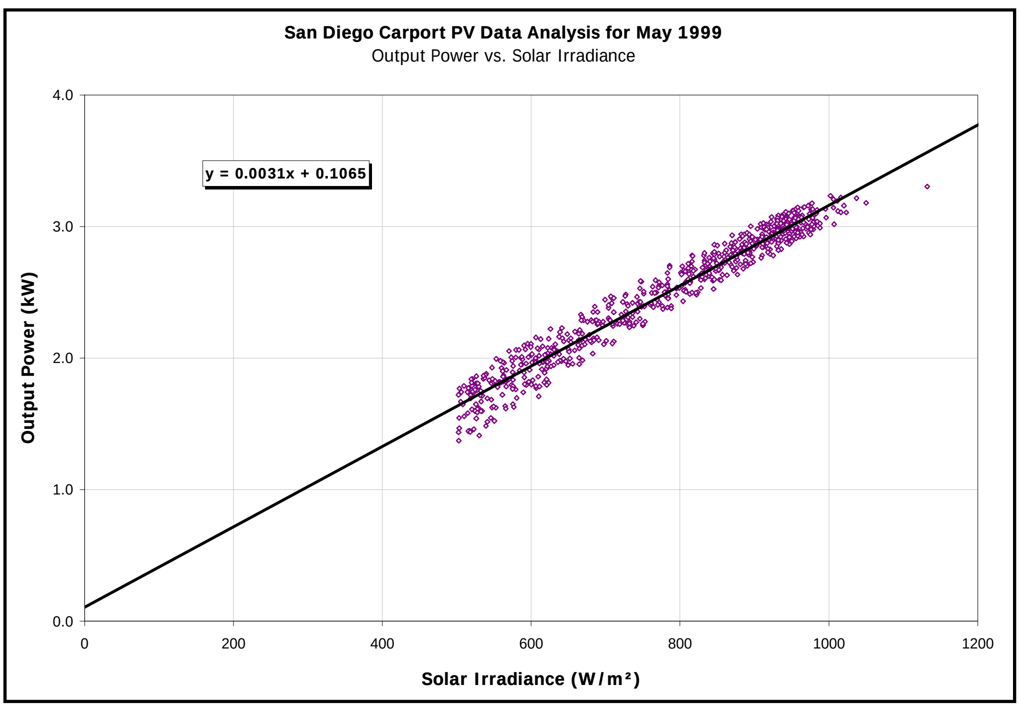

Figure A- 51. Output Power vs. Solar Irradiance - May 1999

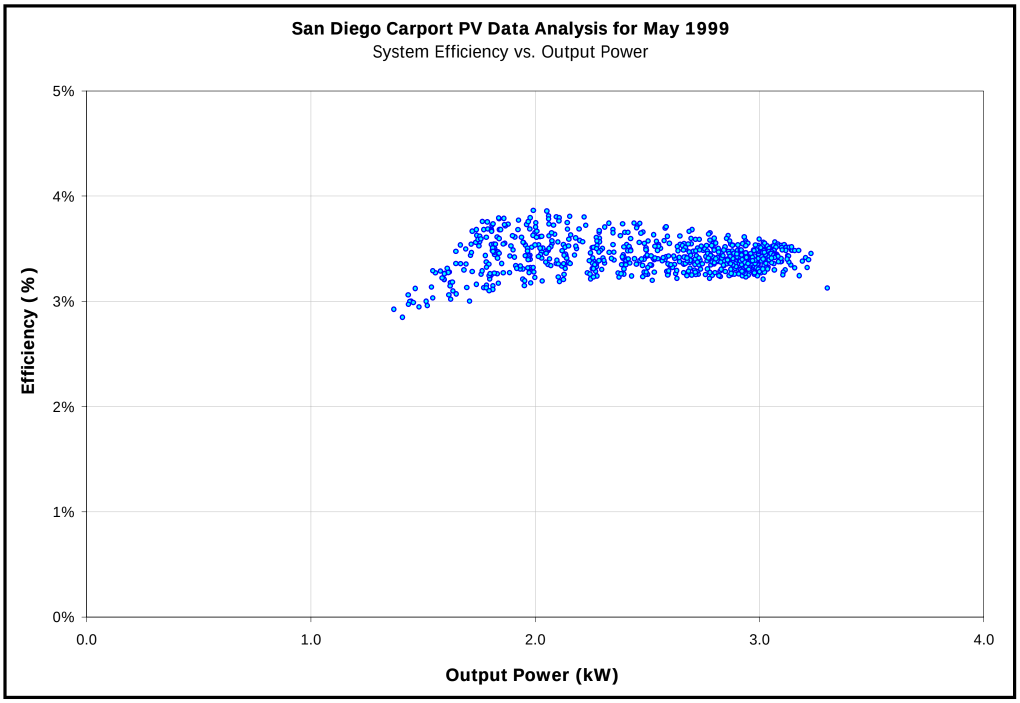

Figure A- 52. Efficiency vs. Output Power - May 1999

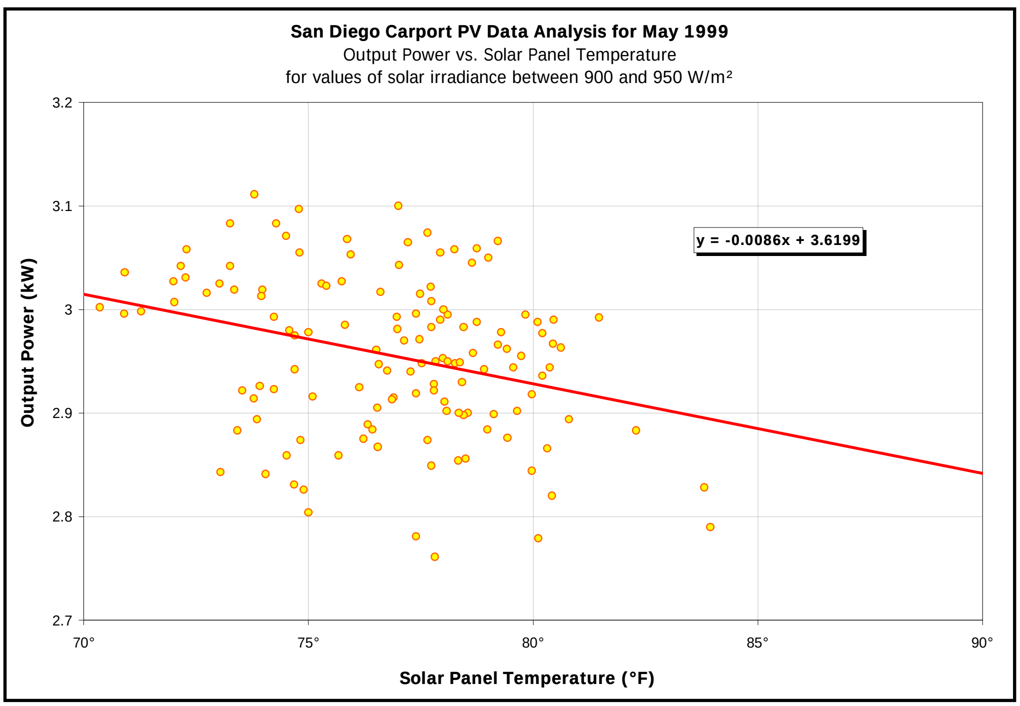

Figure A- 53. Output Power vs. Solar Panel Temperature - May 1999

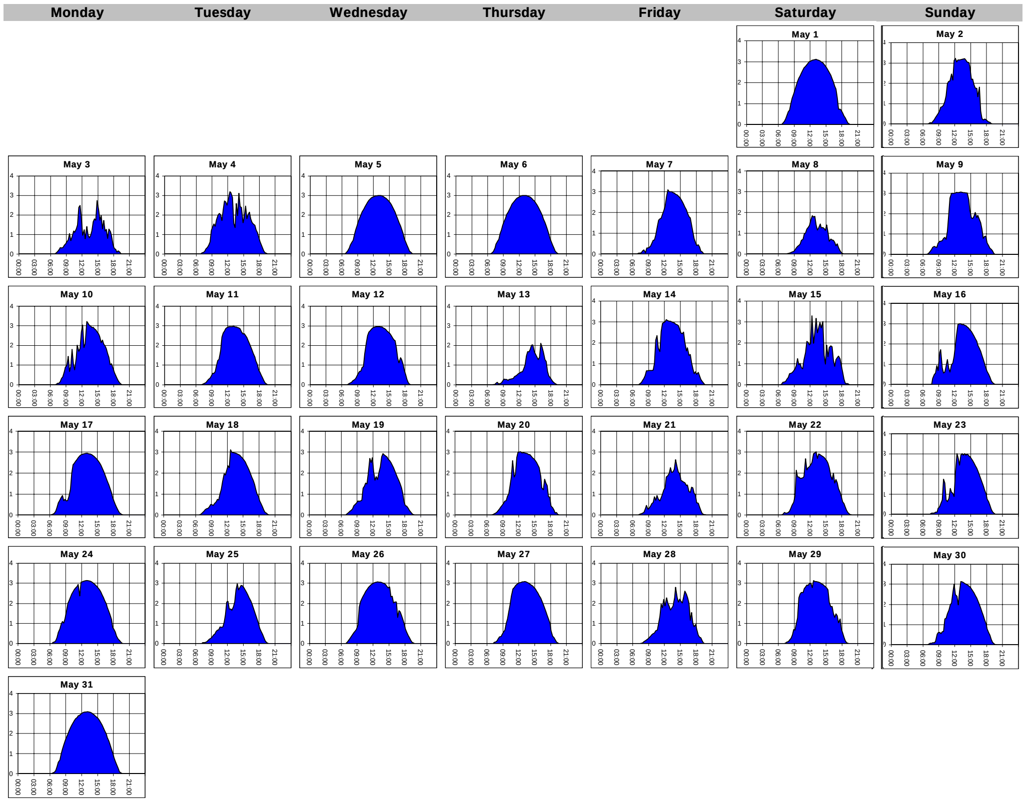

Figure A- 54. PV System Power Output Daily Thumbnails - May 1999

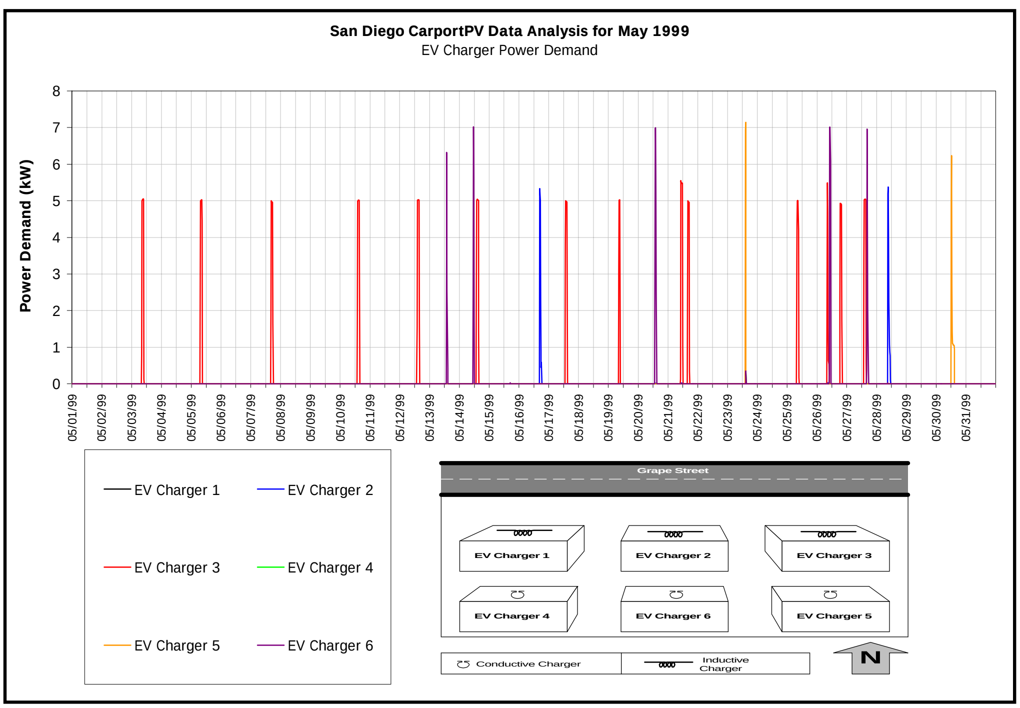

Figure A- 55. EV Charger Demand Profile - May 1999

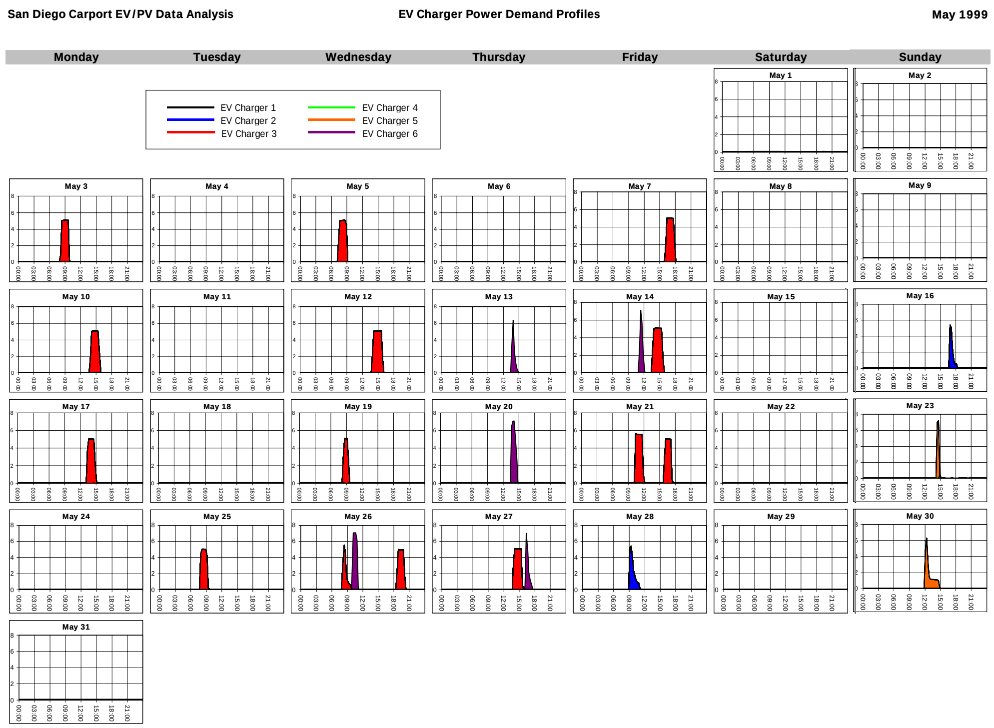

Figure A- 56. EV Charger Usage Daily Thumbnails - May 1999

June 1999

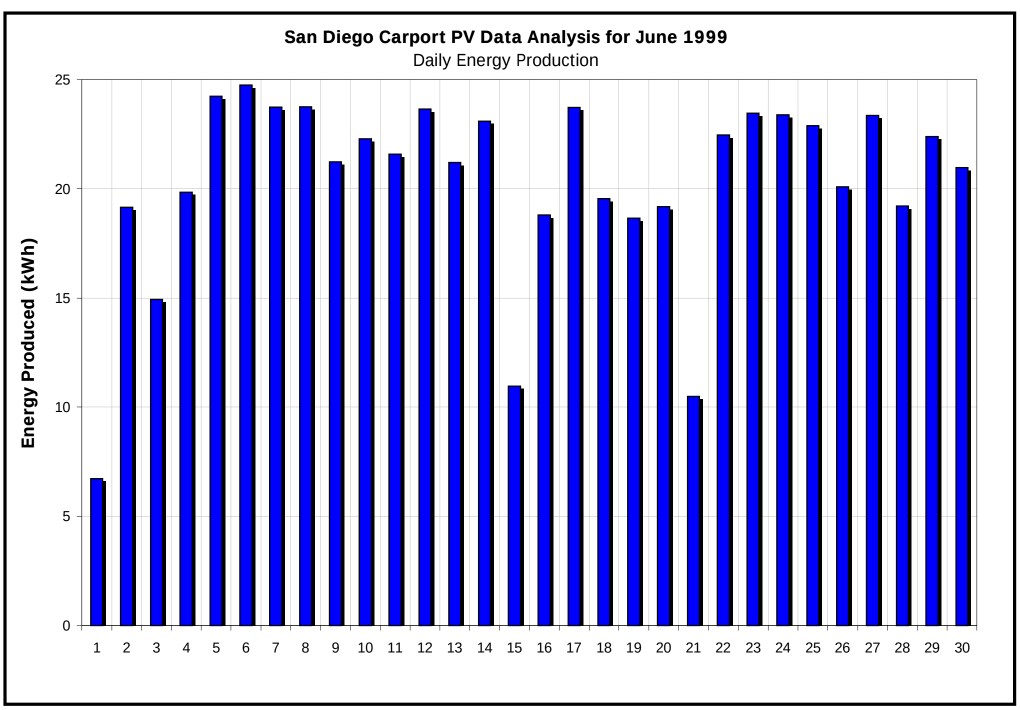

Figure A- 57. Daily Energy Production - June 1999

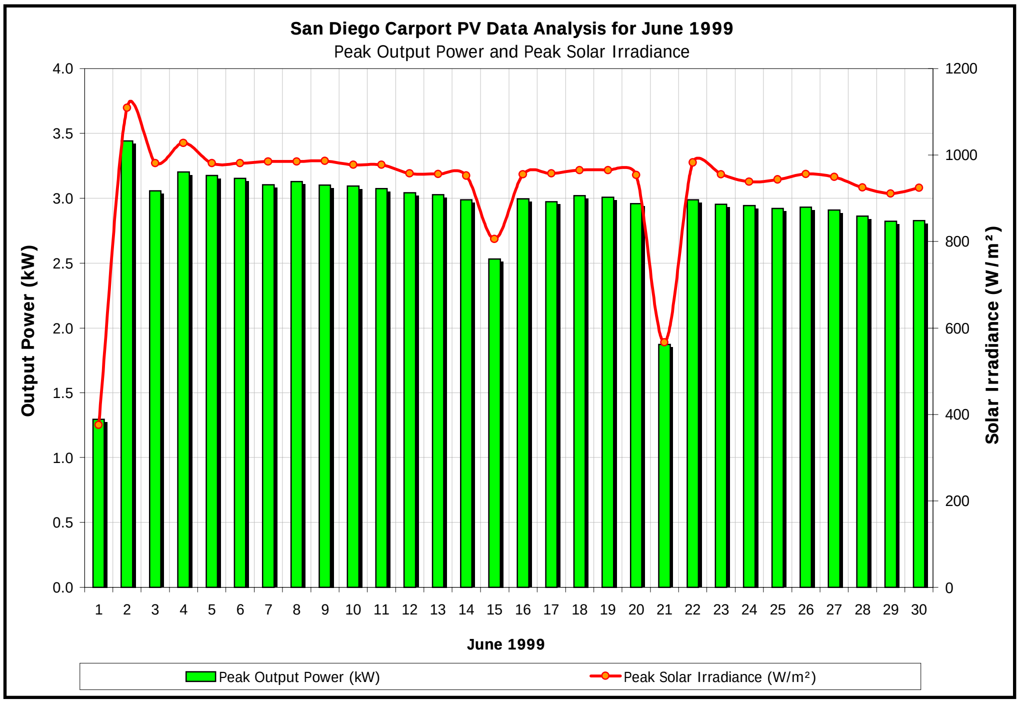

Figure A- 58. Peak Power and Peak Solar Irradiance - June 1999

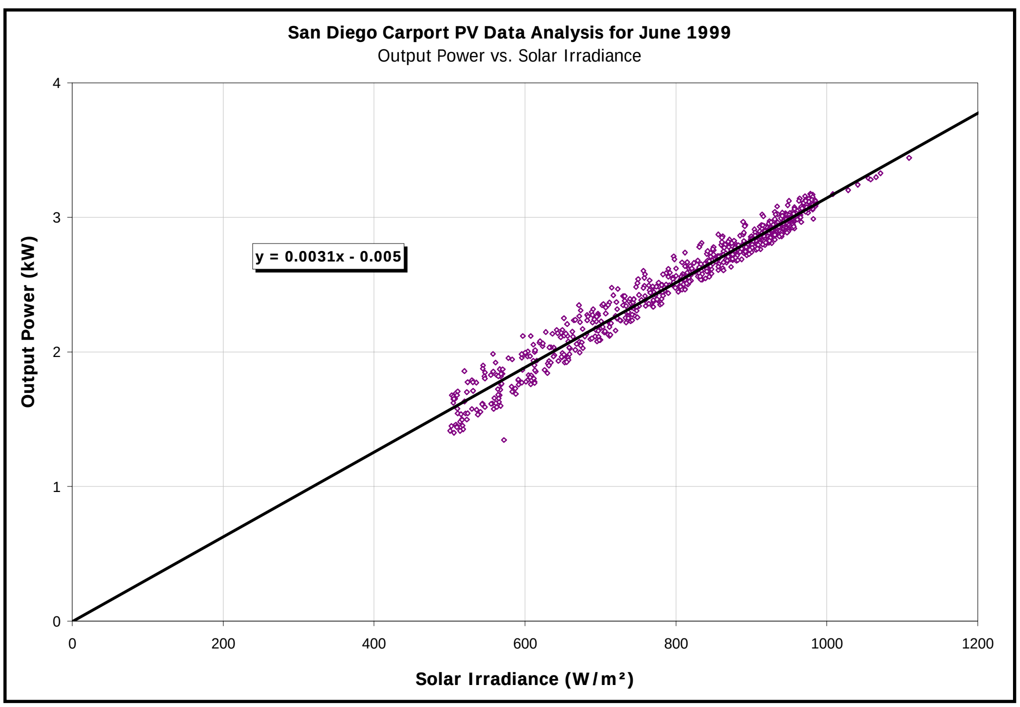

Figure A- 59. Output Power vs. Solar Irradiance - June 1999

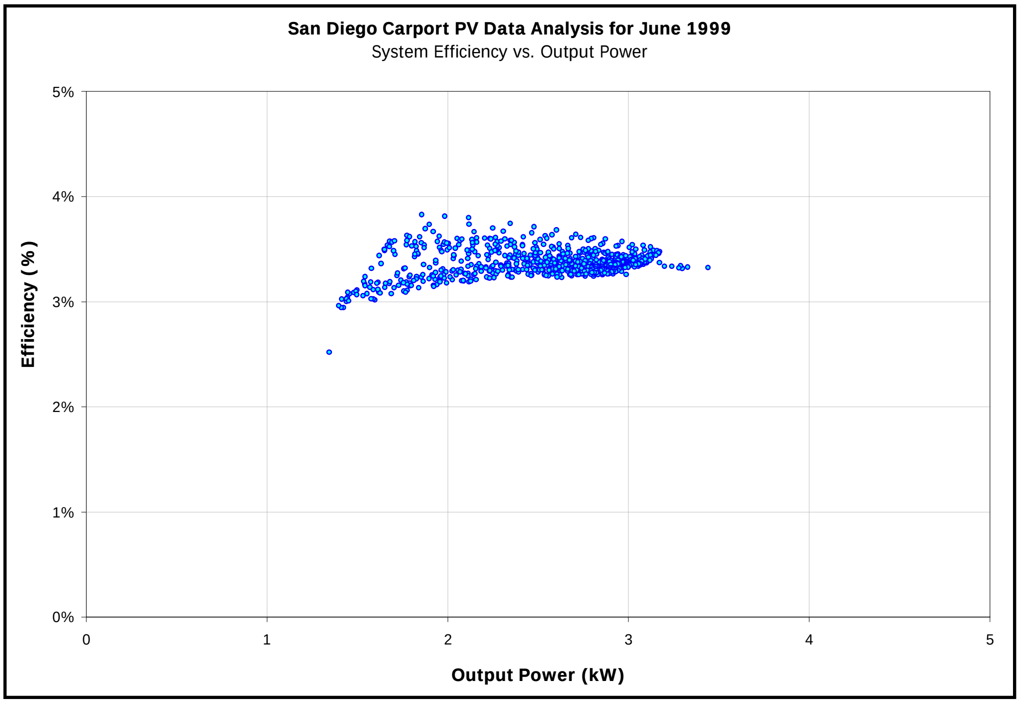

Figure A- 60. Efficiency vs. Output Power - June 1999

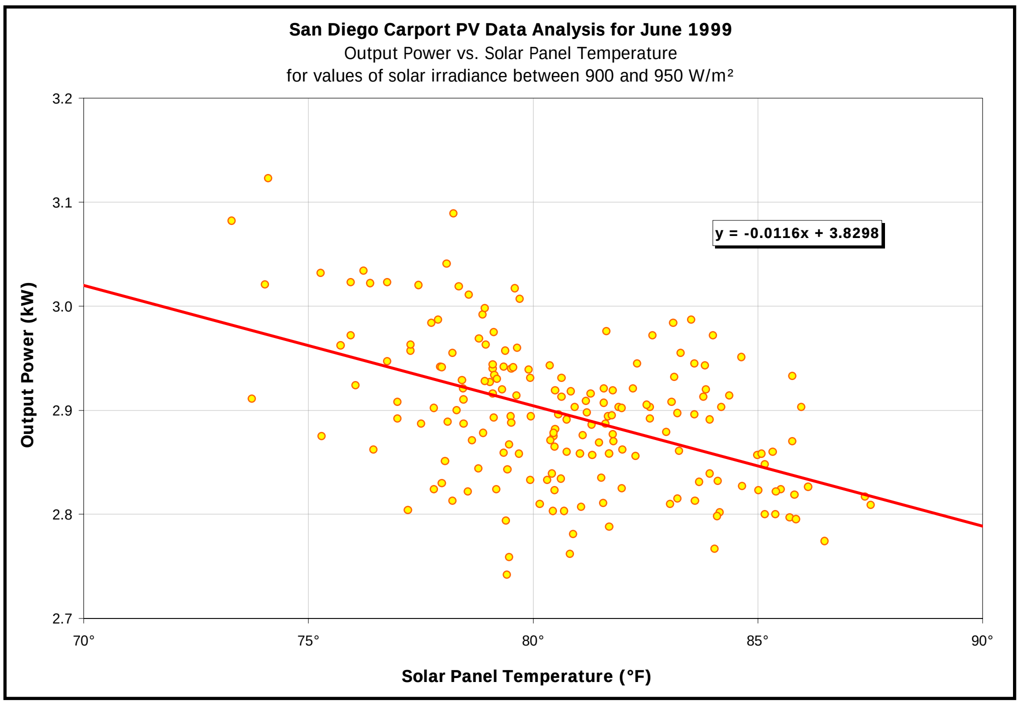

Figure A- 61. Output Power vs. Solar Panel Temperature - June 1999

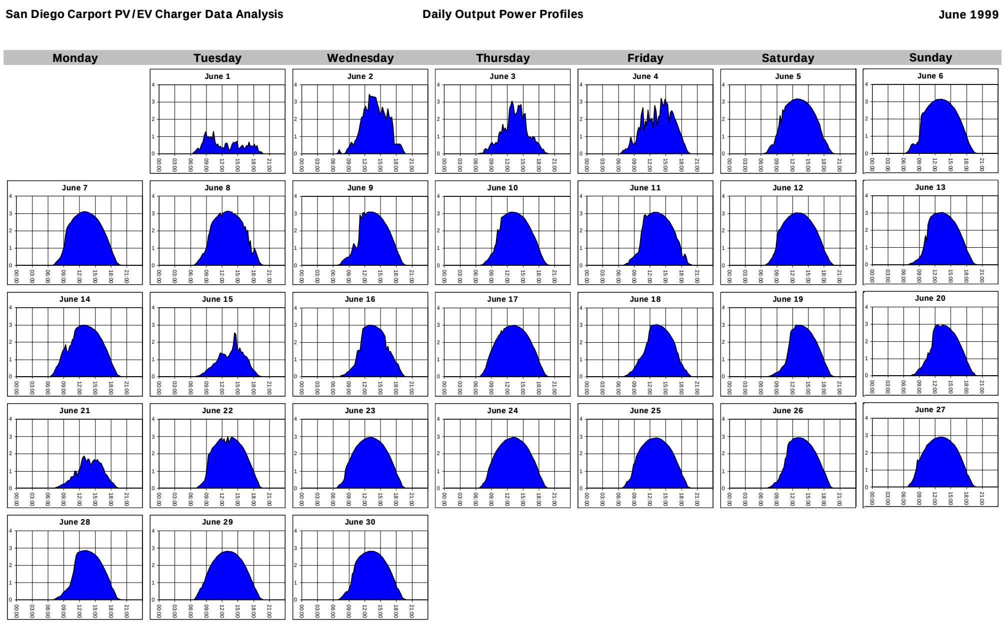

Figure A- 62. PV System Power Output Daily Thumbnails - June 1999

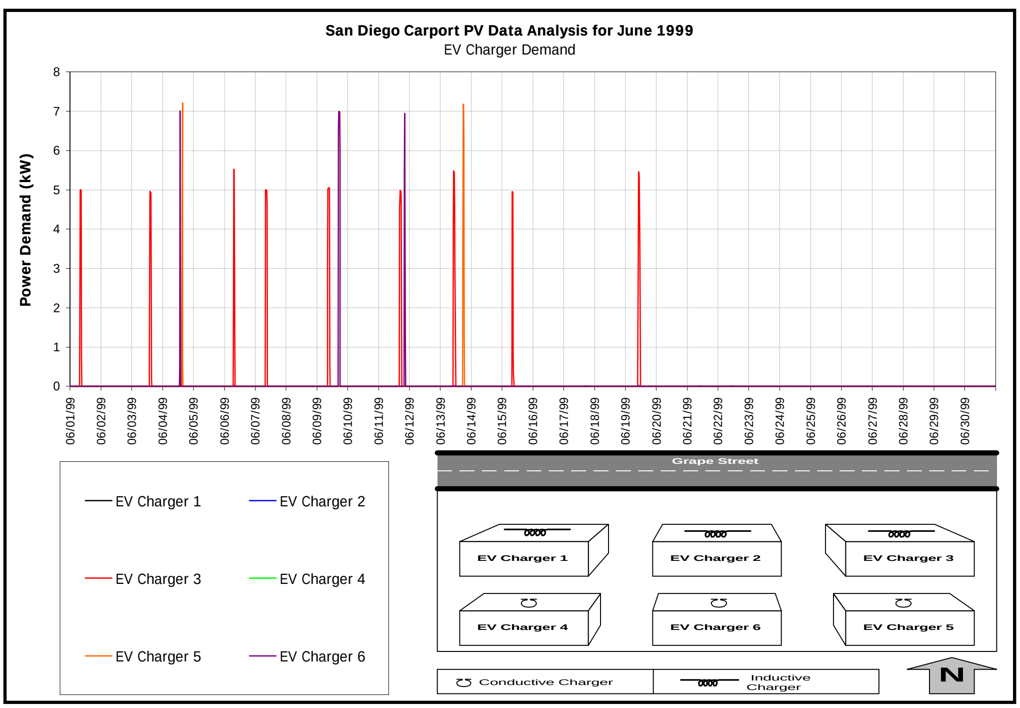

Figure A- 63. EV Charger Demand Profile - June 1999

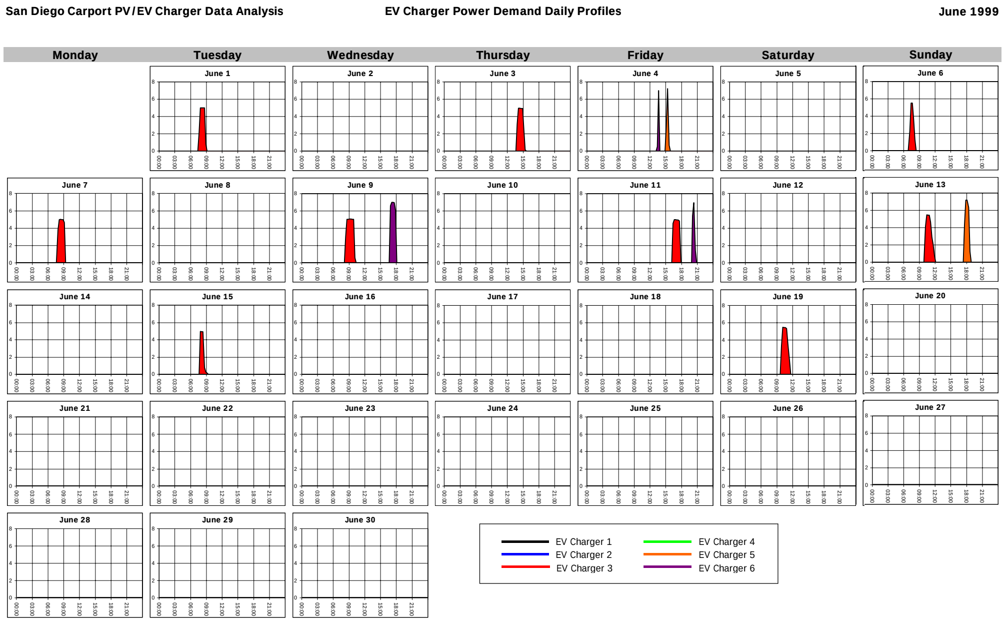

Figure A- 64. EV Charger Usage Daily Thumbnails - June 1999

July 1999

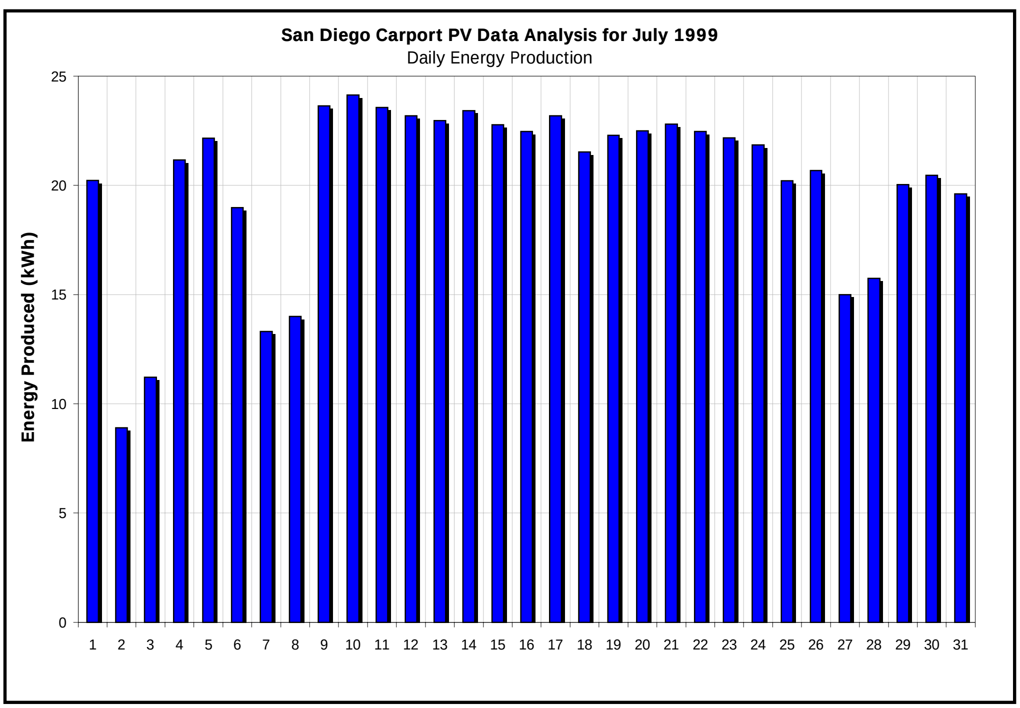

Figure A- 65. Daily Energy Production - July 1999

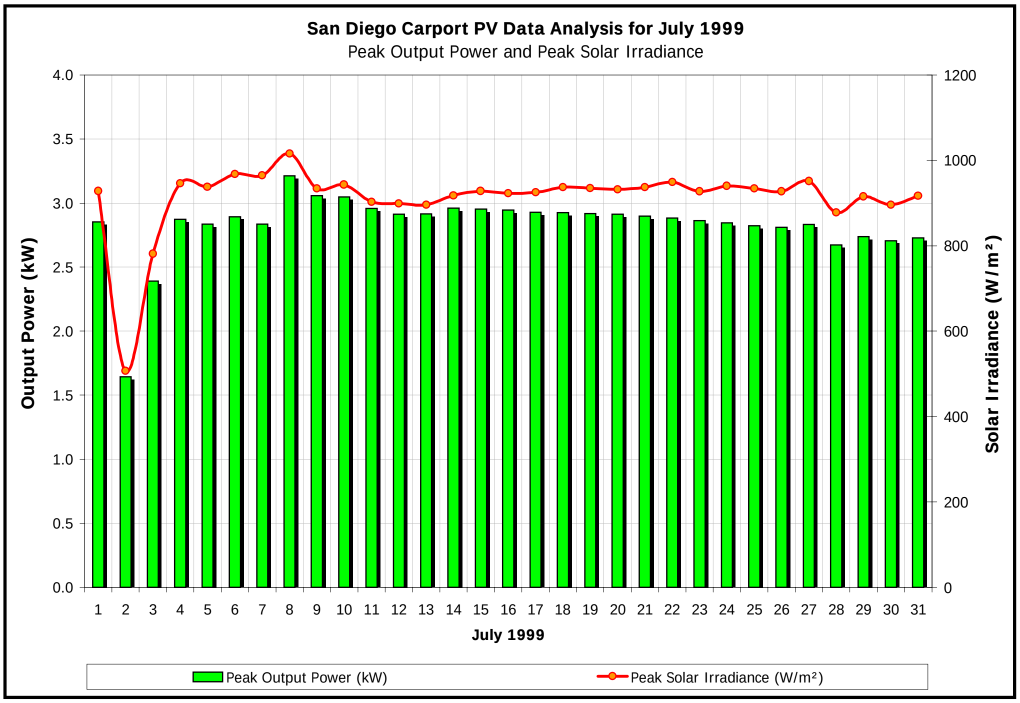

Figure A- 66. Peak Power and Peak Solar Irradiance - July 1999

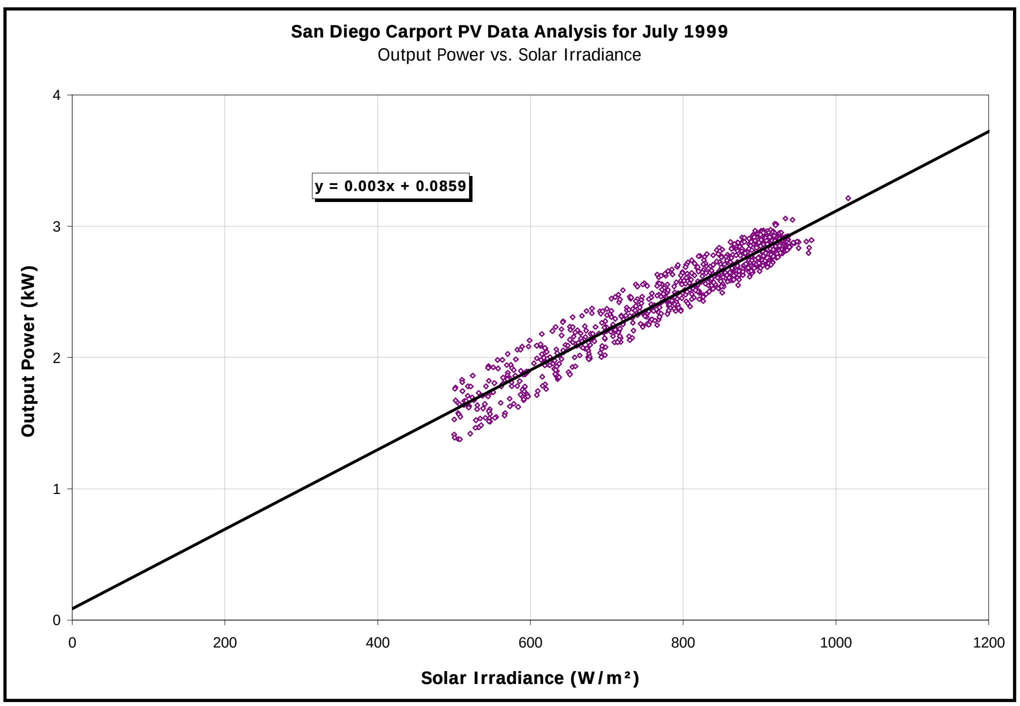

Figure A- 67. Output Power vs. Solar Irradiance - July 1999

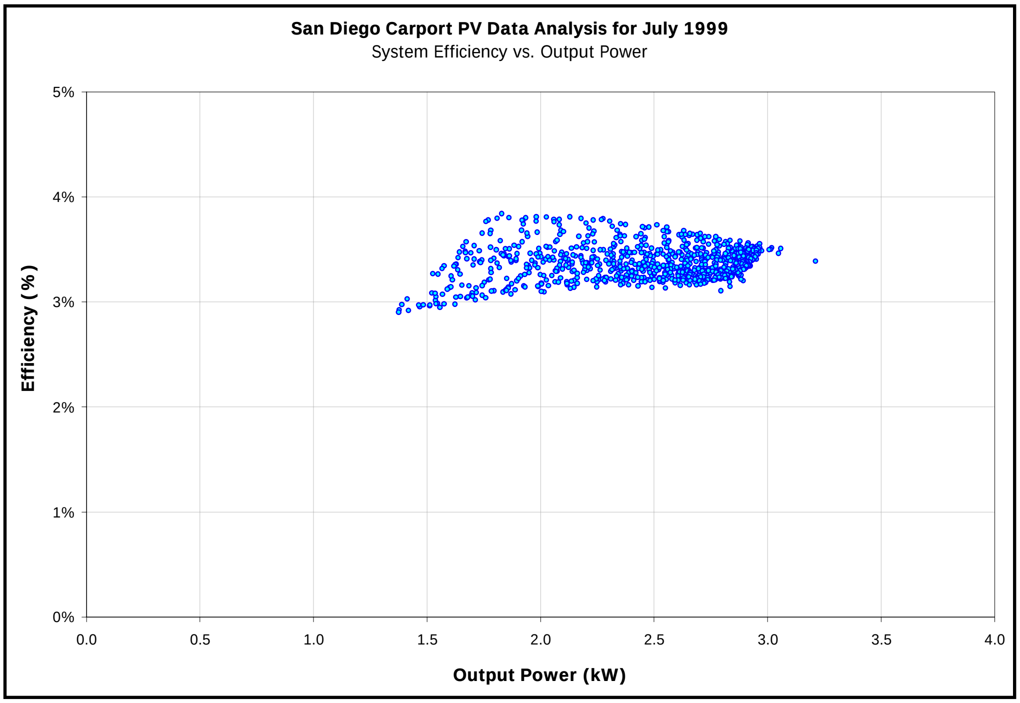

Figure A- 68. Efficiency vs. Output Power - July 1999

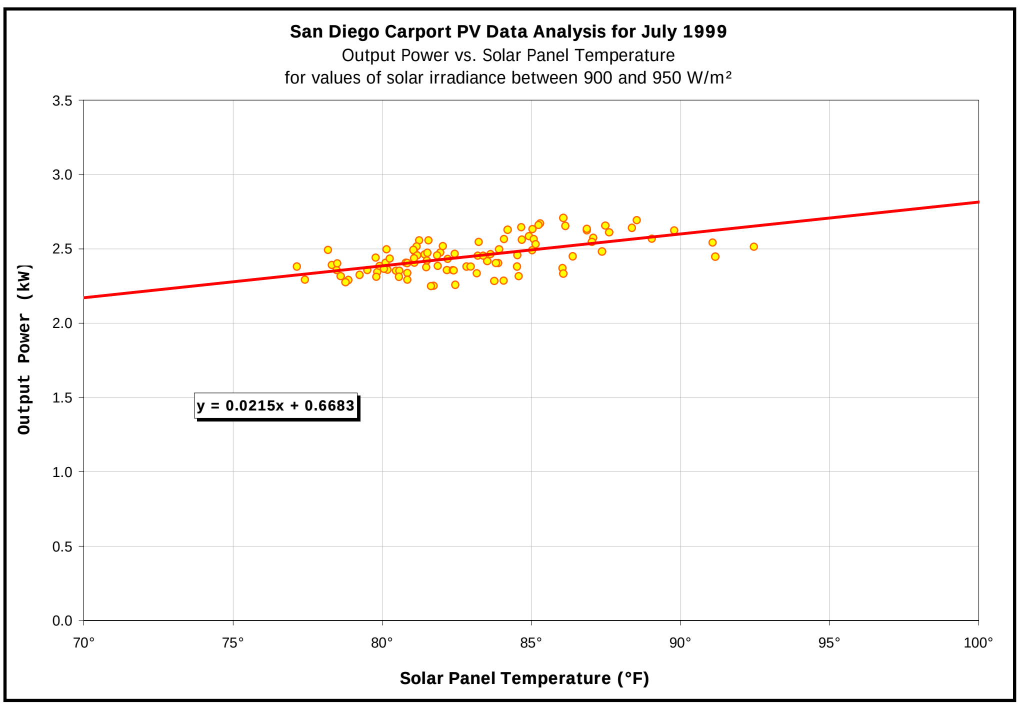

Figure A- 69. Output Power vs. Solar Panel Temperature - July 1999

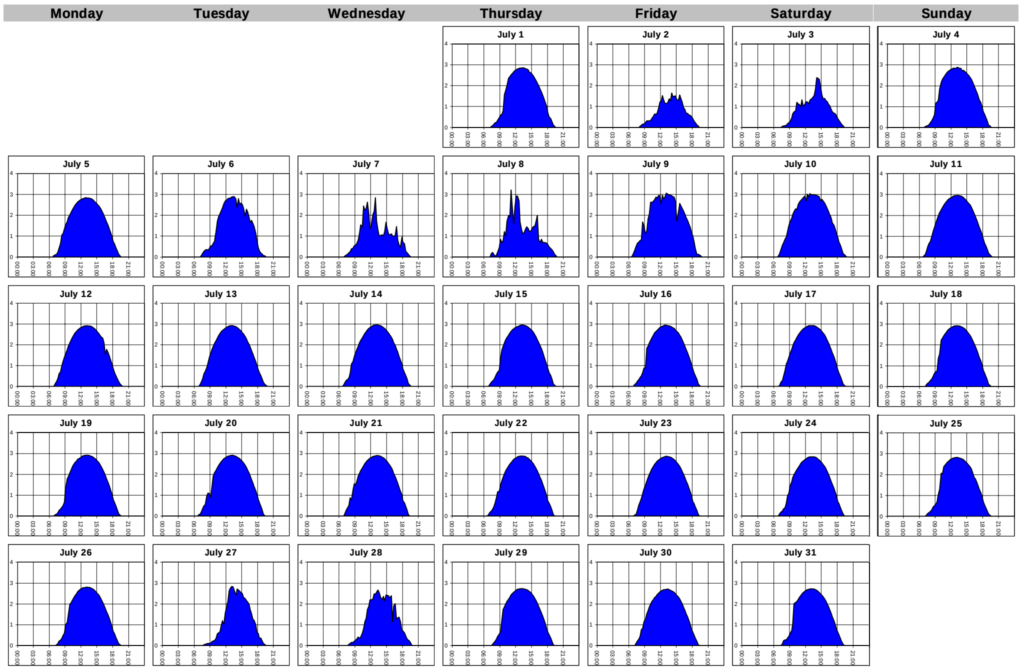

Figure A- 70. PV System Power Output Daily Thumbnails - July 1999

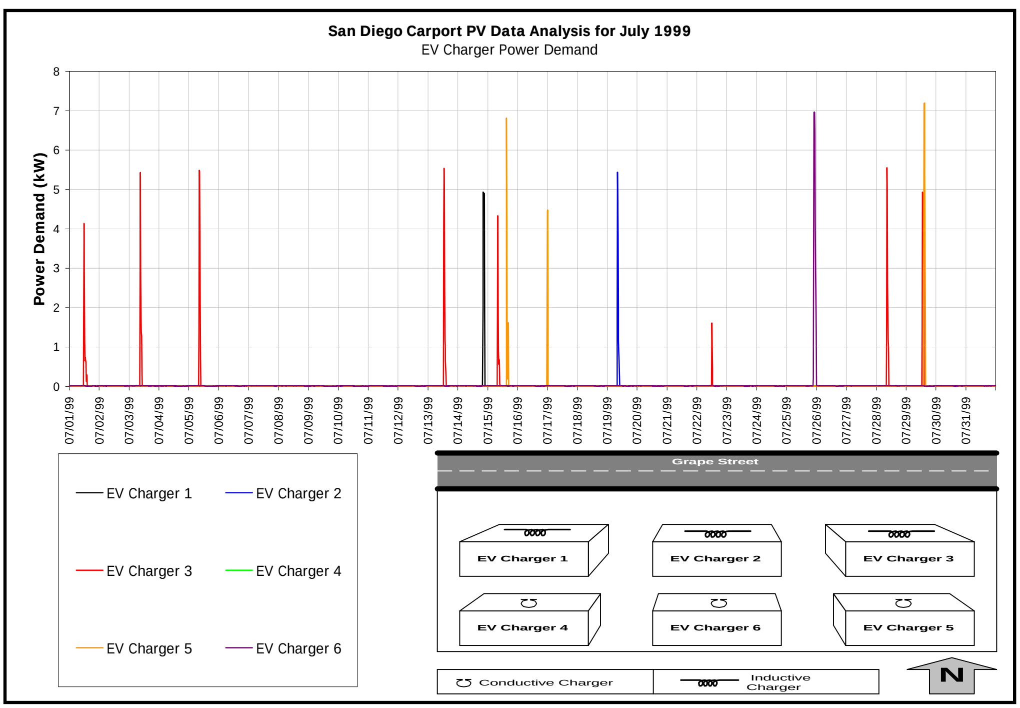

Figure A- 71. EV Charger Demand Profile - July 1999

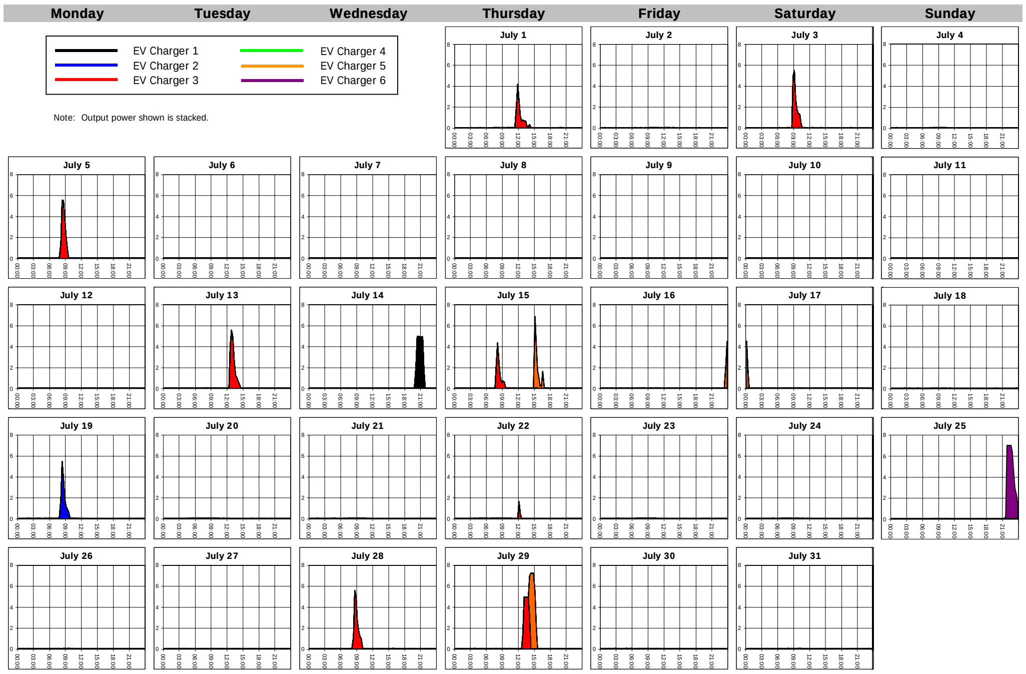

Figure A- 72. EV Charger Usage Daily Thumbnails - July 1999